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Työn nimi The Embrace of the Ocean - a case study in fulldome content-creation

Laitos Department of Media

Koulutusohjelma Visual Communication Design

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Tiivistelmä

"The Embrace of the Ocean" is a fulldome (planetarium) film directed and produced by Pekka Veikkolainen and Hannes Vartiainen. The film premiered at The Finnish Science Centre Heureka in March 2019. The film comprises of live footage shot with several different camera types and animated volumetric data visualization from various sources, rendered with custom in-house software.

In this thesis I break down the reasoning and decisions made during the production of "The Embrace of the Ocean", from the point of view of the film director responsible for the post-production pipeline and final image quality. Namely, how to counteract cross-reflection all the way from the planning phases of the film, such as choices regarding filming equipment, to the final stages of the post-production: the compositing and color grading of the film.

I show that the problem of cross-reflection exists at The Finnish Science Centre Heureka's planetarium through a series of measurements and propose several solutions from shot planning to compositing to minimize the effect through real-world examples implemented in the production of "The Embrace of the Ocean".

Avainsanat planetarium, fulldome, dome master, documentary film, cross-reflection, hemispherical cinema, volumetric data, x-ray tomography, confocal microscopy, compositing, color grading, The Finnish Science Centre Heureka

The Embrace of the Ocean

A CASE STUDY IN FULLDOME CONTENT-CREATION

Bachelor’s Thesis
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Department of Media
Visual Communication Design

Aalto University
School of Arts, Design
and Architecture

2019

Table of Contents

1 INTRODUCTION

This thesis is written in English to make it more accessible to other current and aspiring fulldome content-creators, as the professional Finnish fulldome filmmaking scene is almost non-existent. After producing and directing 3 fulldome shows between 2015 and 2019 together with Hannes Vartiainen, I believe we are the most experienced film production company in Finland dealing with fulldome content-creation at present moment. Therefore I wanted to document the reasoning behind our decision-making that led to the final structure and visual style of *"The Embrace of the Ocean"*, and how the planetarium as a platform for cinematic content influenced those decisions.

I will start by describing what the Dome Master standardt, then introduce the main target cinema for *"The Embrace of the Ocean"* at The Finnish Science Centre Heureka, and explain some of the differences and challenges in creating content for the planetarium dome instead of a normal cinema screen. I will then present a series of tests I conducted at The Finnish Science Centre Heureka's planetarium. The tests show that introducing visual elements haphazardly to the dome can lead to significant problems in projection quality by introducing cross-reflection, or light spilling to undesired areas in the dome. I use both computer-generated test images and real-world examples to make the problem visible.

Cross-reflection is an inherent characteristic of hemispherical projection surfaces, but when designing fulldome content, it can be mitigated with the right kind of decisions made during different phases of production, even if it cannot be completely eliminated.

I will then take a brief look at the human visual system's characteristics, namely the scope of the human visual field and the rate at which the human eye adapts to low-light conditions, and how these characteristics can be used as a basis for making composition and color grading decisions in a fulldome show's post-production phase. Finally, I will provide a breakdown of the types of visual content *"The Embrace of the Ocean"* comprises of and show examples of the main steps that were taken to format different types of footage for suitable viewing in fulldome format. Essentially, how the 115 shots in the final film were produced and the reasoning behind each shot type and how they contributed to the final visual style of the film.

2 BACKGROUND

In 2014 we opened a discussion with The Finnish Science Centre Heureka about possible collaboration. During our discussion it came up that all the planetarium cinema content shown at Heureka is lisenced from international sources. After more discussion, Heureka expressed interest in co-producing the first Finnish feature fulldome show together with us.

We got to work and in December 2015 *"The Secret World of Moths"* had its premiere at Heureka's planetarium. We have since produced two more fulldome films, *"The Baltic Sea"* and *"The Embrace of the Ocean"*, which had their premieres at Heureka's planetarium in June 2018 and March 2019, respectively.

A lot of the decision-making that influenced the look of the final films was based on a process of trial and error by creating and experimenting with various kinds of still images and animated content at Heureka's planetarium over the last 5 years. As footage is being edited on traditional, flat computer screens, it becomes necessary to visit a dome theatre periodically to check results and to develop a feel for the kinds of imagery that might work when projected on the dome surface.

Digital fulldome cinema is quite a recent invention and perhaps not surprisingly, during our journey into creating our fulldome films, others have been wrestling with similar problems. A 2-part article *"Filmmaking for Fulldome: Best Practices and Guidelines for Immersive Cinema"* describing guidelines for filmmaking for fulldome was published in 2016 and 2017 by Yu et al. and it may provide more detailed and useful recommendations for aspiring fulldome filmmakers than this thesis does. This article was, however, not used as a basis for the decision-making in our films, and is mentioned here for the sake of giving the reader more related material to look into.

2.1 HEUREKA'S PLANETARIUM AND THE DOME MASTER FORMAT

2.1.1 DIGITAL ERA IN THE WORLD'S PLANETARIA

Modern planetariums are soon a hundred-year-old invention. The first opto-mechanical planetarium was opened in Jena, Germany, by Carl Zeiss in 1923. For the next several decades the content projected on the inside surface of the dome were depictions of stars and other celestial bodies. (Lantz 2011).

The digitalization of planetarium content is a relatively recent phenomenon. The first vector-based projection systems arrived in the 1980's, and it was only in 1996 the first multi-projector systems were introduced, paving way to the modern digital planetarium cinemas. (Lantz 2011). Thus most of the innovation in the field of fulldome cinema, like fulldome format standardization, fulldome content-oriented film festivals and best practices for content-creation have been taking place only during the 21st century, more specifically in its second decade. (Lambert & Phillips 2012).

At the same time, global planetarium audiences have been growing steadily. Loch Ness Productions, a veteran production company in the field, has been estimating yearly attendance numbers of the various planetaria in the world. Their estimate from January 31, 2019 is that more than 146 million people visited the 4,250 planetaria of the world, of which 1685 are listed as fulldome-capable. (Lochnessproductions.com website, 4.11.2019). This number has more than doubled from 2011, when Loch Ness Productions listed the number of fulldome-capable theatres at 820 (Lantz 2011).

2.1.2 DOME MASTER SPECIFICATION

The Dome Master format is an attempt to standardize digital content across the different kinds of fulldome planetaria around the world. IMERSA Inc. and The Association of Fulldome Innovators (AFDI) list the recommended specifications at IMERSA.org's website.

The part of the Dome Master standard that concerns this thesis is the following: The suitable Dome Master format for providing footage into Heureka's planetarium is a 4096 x 4096 pixel-sized square image sequence running at 30 frames per second, inside which a circle touching all edges defines the visible image borders and contains the projected image. The areas outside the circle in a Dome Master frame are to be black, with the image's metadata written in the top left corner of the file. (Imersa.org website, 4.11.2019)

2.1.3 HEUREKA'S PLANETARIUM

Heureka, The Finnish Science Centre's planetarium is equipped with two Sony SXR T615 HD 4K video projectors, one located at the rim of the dome in the front, the other at the back. The dome's diameter is 17,5 meters and it is tilted forwards at a 23-degree angle. The viewing direction is unidirectional (audience is seated looking in the same way, as opposed to omnidirectional planetaria, where audience may sit in circular arrangements) and it seats 135 viewers at a time. (Heureka, The Finnish Science Centre website, 31.10.2019)

Heureka's planetarium projection system accepts files in Dome Master format. The circular Dome Master images are sliced in-house to separate, suitable images that can be fed to the two projectors. When the images are projected on the dome surface, their faded edges meet half-way across the dome, blending seamlessly together to create an illusion of a singular image that spans the entire dome.

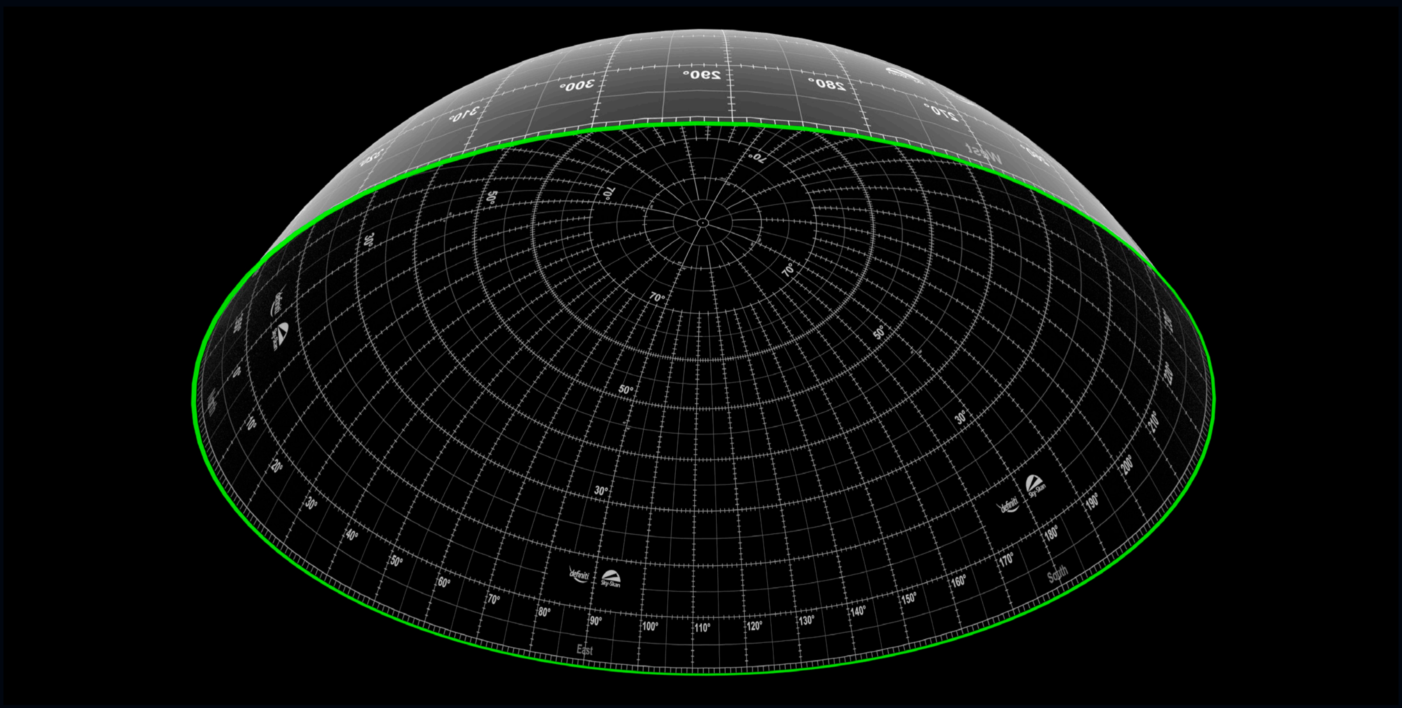


Fig. 1. The Finnish Science Centre Heureka's planetarium calibration image projected on a three-dimensional model.

Heureka's Planetarium

Technical information

Theatre name: Heureka's planetarium
Format: 2D
Projector: 2 Sony SXR T615 HD 4K with custom lenses
Projector system: Sky-Skan Definiti System
Projector type: Digital
Screen type: Dome
Seating Capacity: 135
Theatre Opened: 1989 (renovated in 2007, 2011)
Dome Screen Diameter: 17,5 m
Tilt: 23 degrees

Fig. 2. An example of a hemispherical still frame from *"The Embrace of the Ocean"*.

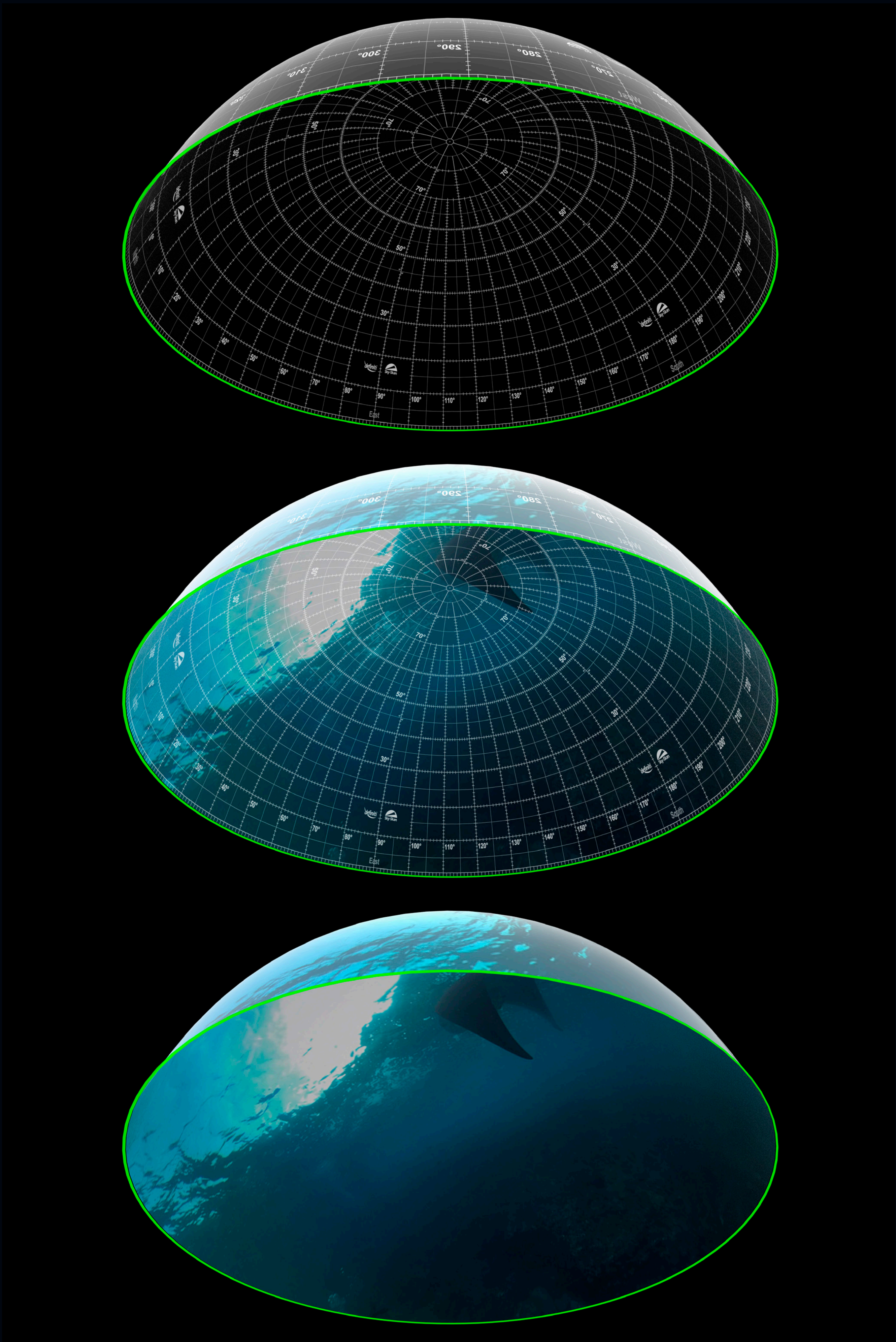


Fig. 3. The Sky-Skan Infiniti grid and Boxfish 360 fisheye projection still from *"The Embrace of the Ocean"* overlaid.

2.2 CROSS-REFLECTION

2.2.1 WHAT IS CROSS-REFLECTION?

In a typical cinema the image is front-projected to a screening surface from a projector situated behind the audience's back. The projected light bounces off the screen and reaches the audience. Heureka's planetarium works mostly in the same way, by using two projectors, one in the front of the dome and one in the back. Together the two projectors fill the whole projection surface with image.

The notable difference is that the planetarium screen curves strongly forming a hemispherical surface. Light projected to the dome will not only bounce towards the audience, but it will spill to other parts of the dome as well, creating cross-reflection. This means that bright areas of pixels projected on the dome will spill light on areas that were meant to be dark, reducing the projected image's contrast and filling an image's shadows partially. The end result is seen by the audience as a kind of milky, washed-out image. The amount of cross-reflection increases with light power, eating away at the contrast. Lower light amount gives a better contrast in the image, but human visual system begins to struggle when light levels reach low-enough levels. (Rößner et al. 2016).

2.2.2 CROSS-REFLECTION IN HEUREKA'S PLANETARIUM

To see if the problem of cross-reflection actually exists in Heureka's planetarium, I created a series of test images in Dome Master format and projected them on the dome surface. To measure changes in the amount of light bouncing around in the dome, I placed a Sony a7 III digital camera inside the dome theatre. I then took a series of photographs of the dome front while the different Dome Master test images were projected on the dome.

The camera was set on manual mode and pointed at the front of the dome, where audience is likely to look. The series of test images was then projected in the dome, with a photograph taken of the front of the dome of each test image. The series of test images included both uniform areas of black, white, red, green and blue pixels, as well as mixtures of areas of uniform color and a real-world underwater still image.

The photographs were then taken to Adobe Photoshop CC. Photoshop offers measurement tools for counting the total brightness of a given area in an image, as well as the minimum, maximum, mean and average values of all the selected pixels. As each photograph was taken in succession with identical camera settings, without moving the camera, comparing the brightness values of the individual photographs should reveal if the amount of light being scattered around the dome was measurable.

The test photos revealed that cross-reflection in Heureka's planetarium is not only visible to the naked eye, but also measurable using an off-the-shelf digital camera system.

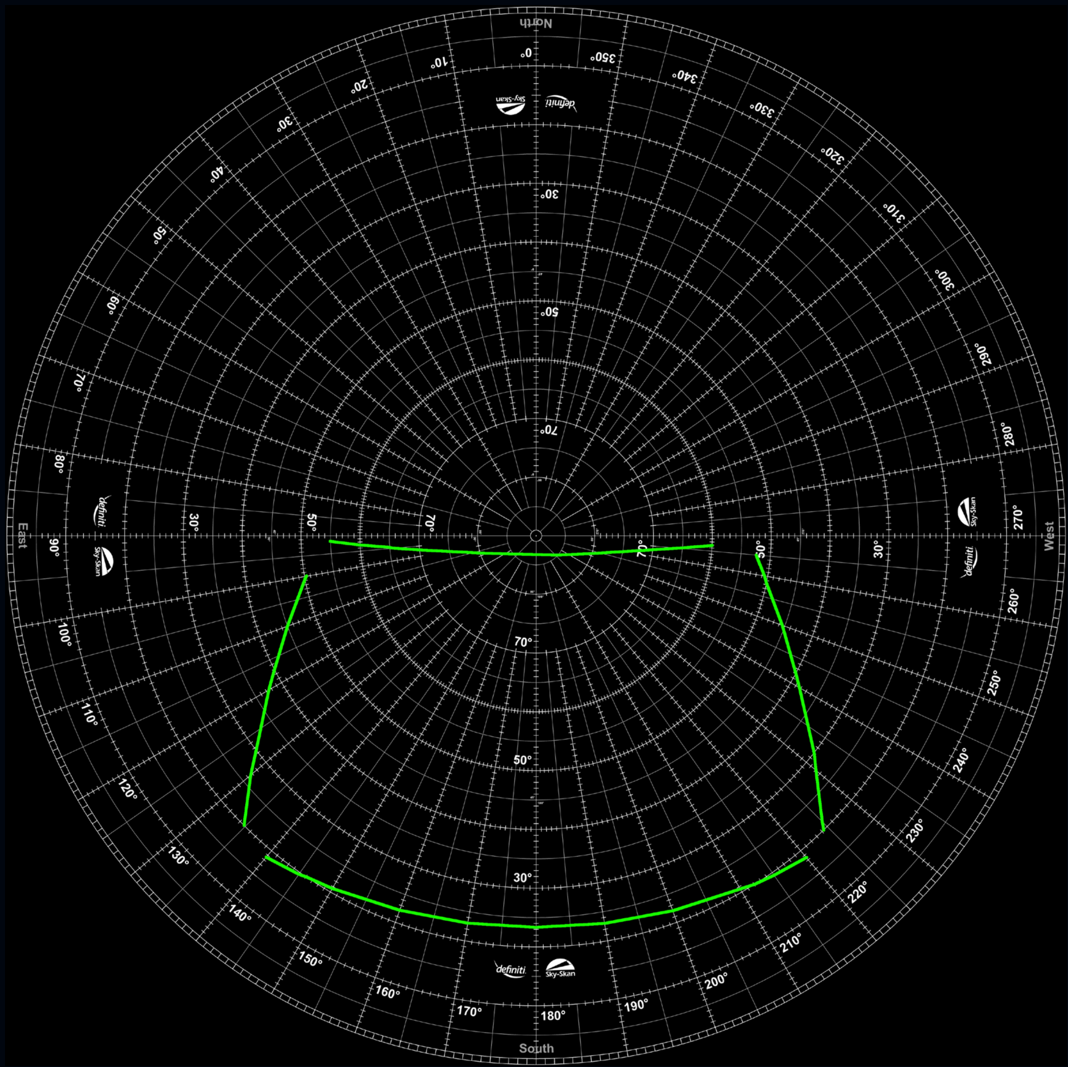


Fig. 4. Area that was photographed inside Heureka's planetarium highlighted in green.

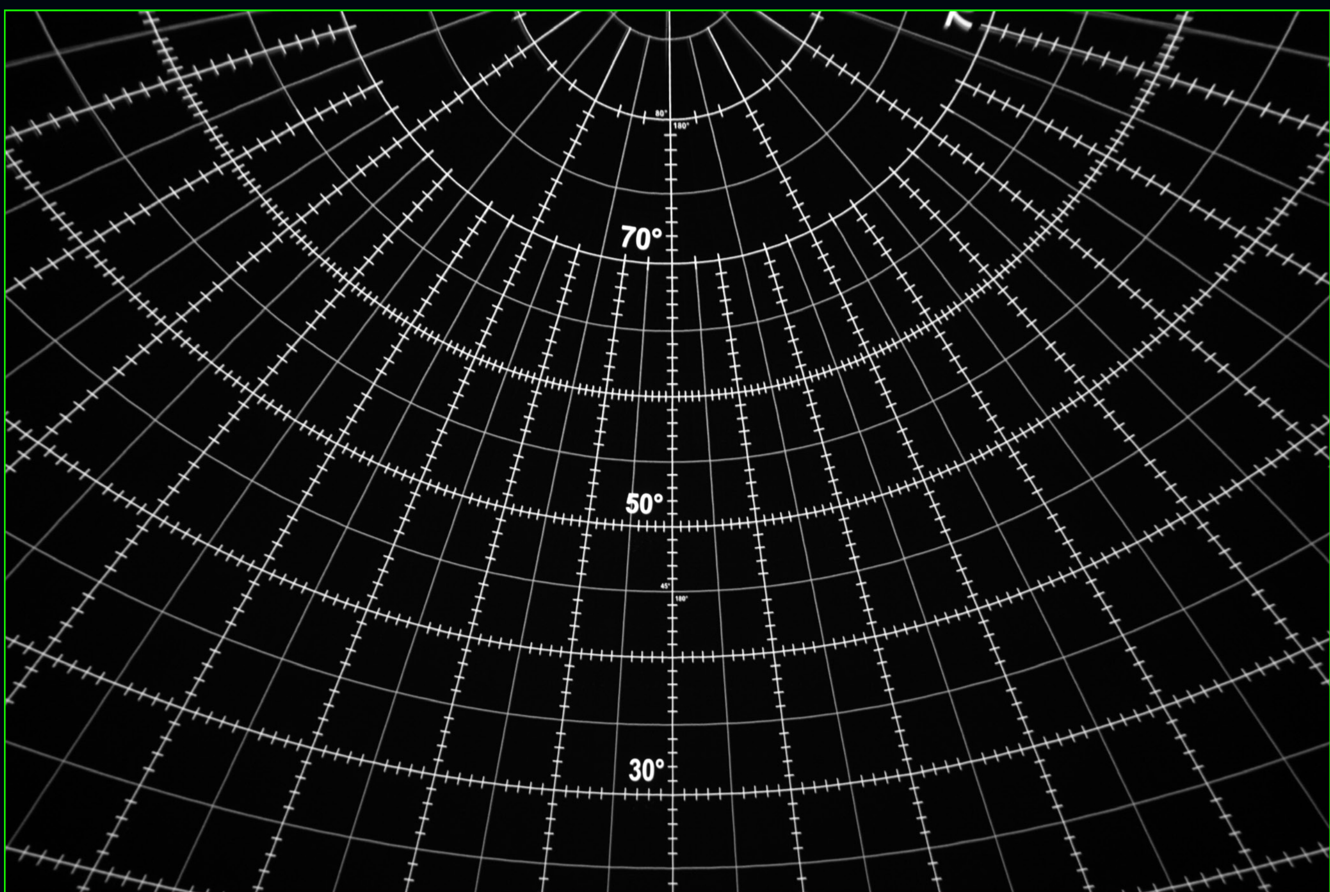
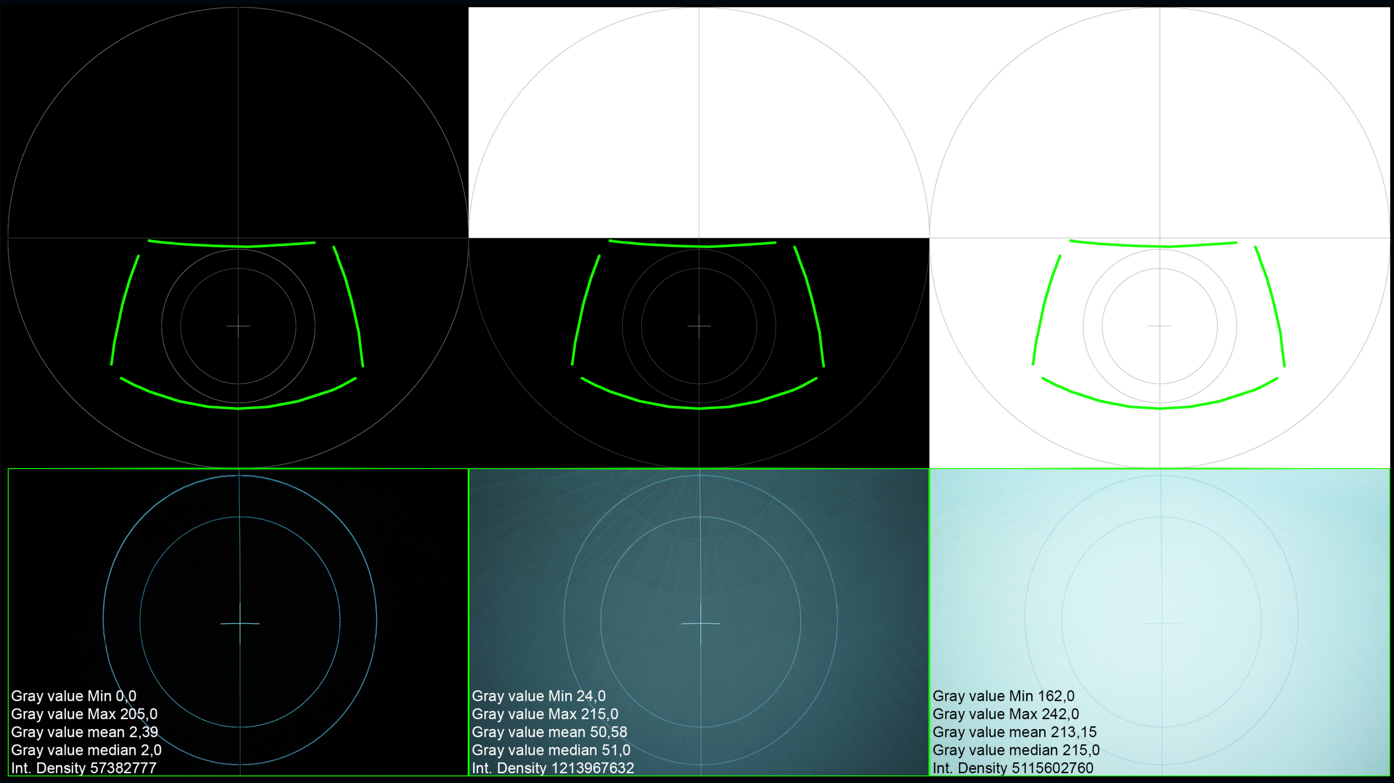


Fig. 5. Digital photograph showing roughly the hotspot area in the dome.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Gray value Max 205,0
Gray value mean 2,39
Gray value median 2,0
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Gray value Min 24,0
Gray value Max 215,0
Gray value mean 50,58
Gray value median 51,0
Int. Density 1213967632
Gray value Min 162,0
Gray value Max 242,0
Gray value mean 213,15
Gray value median 215,0
Int. Density 5115602760

Fig. 6.

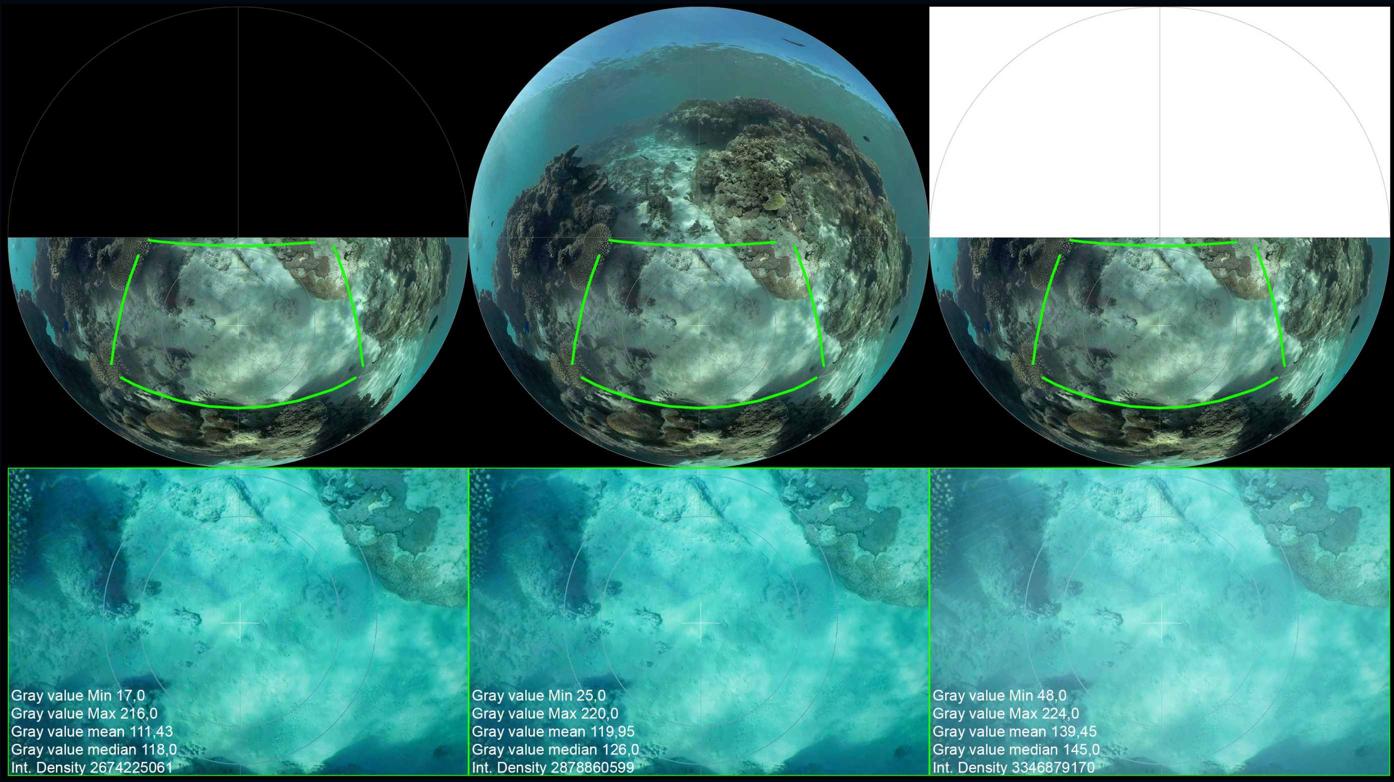

Gray value Min 17,0
Gray value Max 216,0
Gray value mean 111,43
Gray value median 118,0
Int. Density 2674225061
Gray value Min 25,0
Gray value Max 220,0
Gray value mean 119,95
Gray value median 126,0
Int. Density 2878860599
Gray value Min 48,0
Gray value Max 224,0
Gray value mean 139,45
Gray value median 145,0
Int. Density 3346879170

Fig. 7.

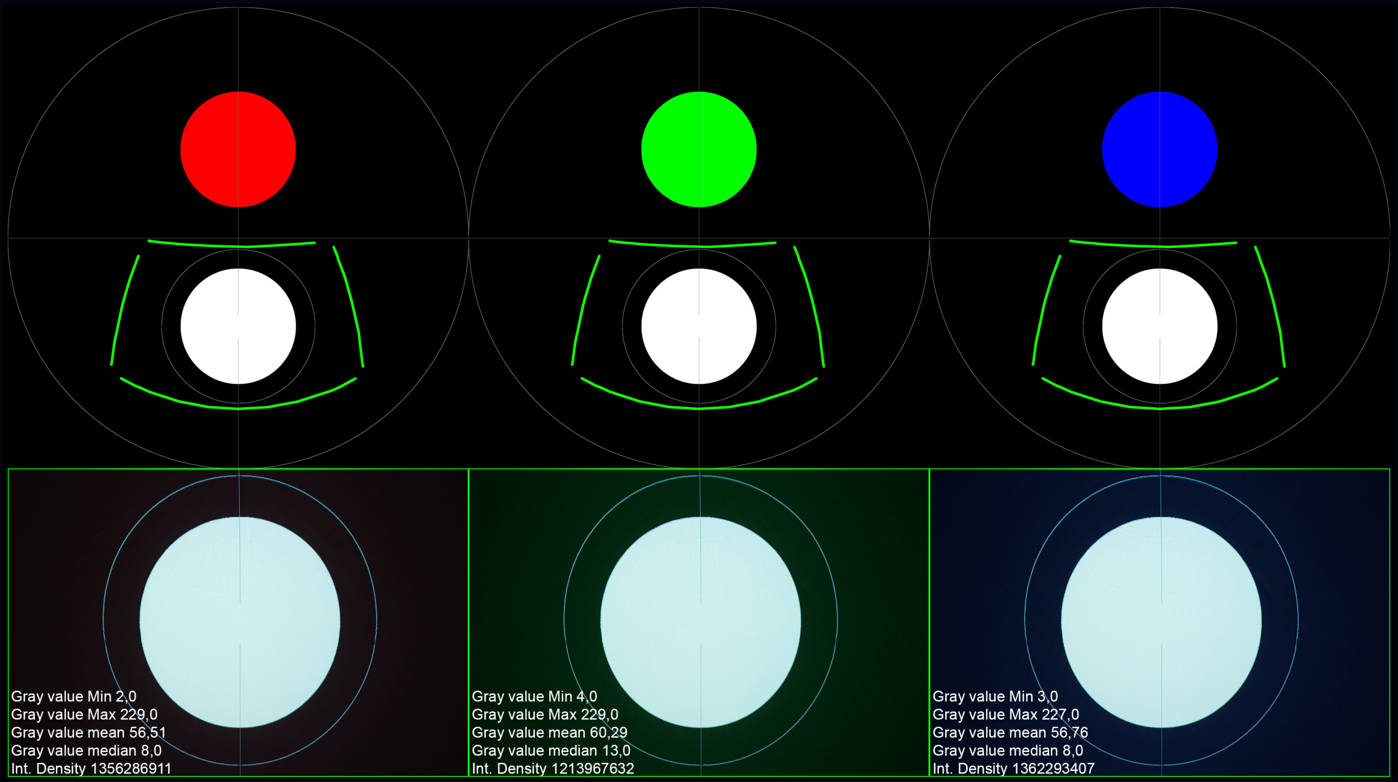
Fig. 6.
Top row, from left to right: Cross-reflection measurement images created in Processing, with green cropmarks overlaid for clarity.
Bottom row, from left to right: Photographs from inside Heureka's planetarium, showing the area of dome inside green cropmarks.

1. Front half of dome filled with black pixels, excluding the targeting grid. Back half of dome filled with black pixels.
2. Front half of dome filled with black pixels, excluding the targeting grid. Back half of dome filled with white pixels.
3. The whole dome filled with white pixels, excluding the targeting grid.

Fig. 7.
Top row, from left to right: Cross-reflection measurement images created in Processing, with green cropmarks overlaid for clarity.
Bottom row, from left to right: Photographs from inside Heureka's planetarium, showing the area of dome inside green cropmarks.

1. Front half of dome filled with black pixels, excluding the targeting grid. Back half of dome filled with black pixels.
2. Underwater video still, no editing.
3. Back half of dome filled with white pixels, excluding the targeting grid.

Photo credit: Boxfish Research Ltd.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Gray value mean 56,51
Gray value median 8,0
Int. Density 1356286911
Gray value Min 4,0
Gray value Max 229,0
Gray value mean 60,29
Gray value median 13,0
Int. Density 1213967632
Gray value Min 3,0
Gray value Max 227,0
Gray value mean 56,76
Gray value median 8,0
Int. Density 1362293407

Fig. 8.

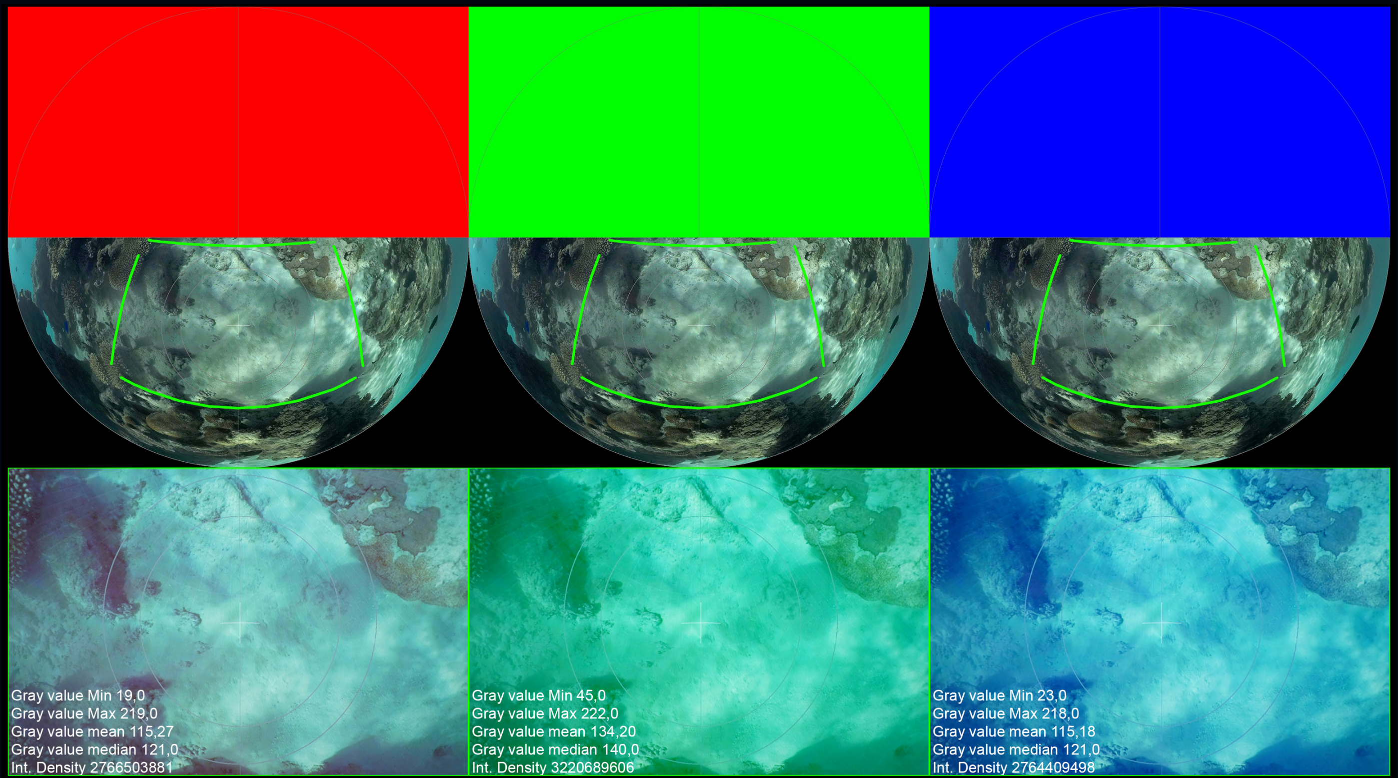

Gray value Min 19,0
Gray value Max 219,0
Gray value mean 115,27
Gray value median 121,0
Int. Density 2766503881
Gray value Min 45,0
Gray value Max 222,0
Gray value mean 134,20
Gray value median 140,0
Int. Density 3220689606
Gray value Min 23,0
Gray value Max 218,0
Gray value mean 115,18
Gray value median 121,0
Int. Density 2764409498

Fig. 9.

Fig. 8.
Top row, from left to right: Cross-reflection measurement images created in Processing, with green cropmarks overlaid for clarity.
Bottom row, from left to right: Photographs from inside Heureka's planetarium, showing the area of dome inside green cropmarks.

1. Front half of dome filled with black pixels, excluding the targeting grid. Back half of dome filled with black pixels.
2. Front half of dome filled with black pixels, excluding the targeting grid. Back half of dome filled with white pixels.
3. The whole dome filled with white pixels, excluding the targeting grid.

Fig. 9.
Top row, from left to right: Cross-reflection measurement images created in Processing, with green cropmarks overlaid for clarity.
Bottom row, from left to right: Photographs from inside Heureka's planetarium, showing the area of dome inside green cropmarks.

1. Front half of dome filled with black pixels, excluding the targeting grid. Back half of dome filled with black pixels.
2. Underwater video still, no editing.
3. Back half of dome filled with white pixels, excluding the targeting grid.

Photo credit: Boxfish Research Ltd.

2.2.3 CROSS-REFLECTION MEASUREMENTS

Fig. 6.

Gray value min 0,0	Gray value min 24,0	Gray value min 162,0
Gray value max 205,0	Gray value max 215,0	Gray value max 242,0
Gray value mean 2,39	Gray value mean 50,58	Gray value mean 213,15
Gray value median 2,0	Gray value median 51,0	Gray value median 215,0
Int. Density 57382777	Int. Density 1213967632	Int. Density 5115602760

Fig. 7.

Gray value min 17,0	Gray value min 25,0	Gray value min 48,0
Gray value max 216,0	Gray value max 220,0	Gray value max 224,0
Gray value mean 111,43	Gray value mean 119,95	Gray value mean 139,45
Gray value median 118,0	Gray value median 126,0	Gray value median 145,0
Int. Density 2674225061	Int. Density 2878860599	Int. Density 3346879170

Fig. 8.

Gray value min 2,0	Gray value min 4,0	Gray value min 3,0
Gray value max 229,0	Gray value max 229,0	Gray value max 227,0
Gray value mean 56,51	Gray value mean 60,29	Gray value mean 56,76
Gray value median 8,0	Gray value median 13,0	Gray value median 8,0
Int. Density 1356286911	Int. Density 1213967632	Int. Density 1362293407

Fig. 9.

Gray value min 19,0	Gray value min 45,0	Gray value min 23,0
Gray value max 219,0	Gray value max 222,0	Gray value max 218,0
Gray value mean 115,27	Gray value mean 134,20	Gray value mean 115,18
Gray value median 121,0	Gray value median 140,0	Gray value median 121,0
Int. Density 2766503881	Int. Density 3220689606	Int. Density 2764409498

EXIF

Brightness Value: -5,955
Color Space: sRGB
Components Configuration: 1, 2, 3, 0
Compressed Bits Per Pixel: 2
Contrast: Normal
Custom Rendered: Normal process
Date Time Digitized: 25 Apr 2019 at 21.47.37
Date Time Original: 25 Apr 2019 at 21.47.37
Digital Zoom Ratio: 1
Exif Version: 2.3.1
Exposure Bias Value: 0
Exposure Mode: Manual exposure
Exposure Program: Manual
Exposure Time: 8
File Source: DSC
Flash: Off, did not fire
FlashPix Version: 1.0
FNumber: 8
Focal Length: 24
Focal Length In 35mm Film: 24

Photographic Sensitivity (ISO): 400
Lens Model: FE 16-35mm F4 ZA OSS
Lens Specification: 16, 35, 4, 4
Light Source: unknown
Max Aperture Value: 4
Metering Mode: Pattern
Pixel X Dimension: 6 000
Pixel Y Dimension: 4 000
RecommendedExposureIndex: 400
Saturation: Normal
Scene Capture Type: Standard
Scene Type: A directly photographed image
SensitivityType: Recommended exposure index (REI)
Sharpness: Normal
White Balance: Manual white balance
Flash Compensation: 0
Image Stabilization: Panning
Lens ID: 65 535
Lens Model: Sony FE 16-35mm F4.0 ZA OSS

Fig. 10. Sony a7 III camera settings used for crossreflection measurement photography.

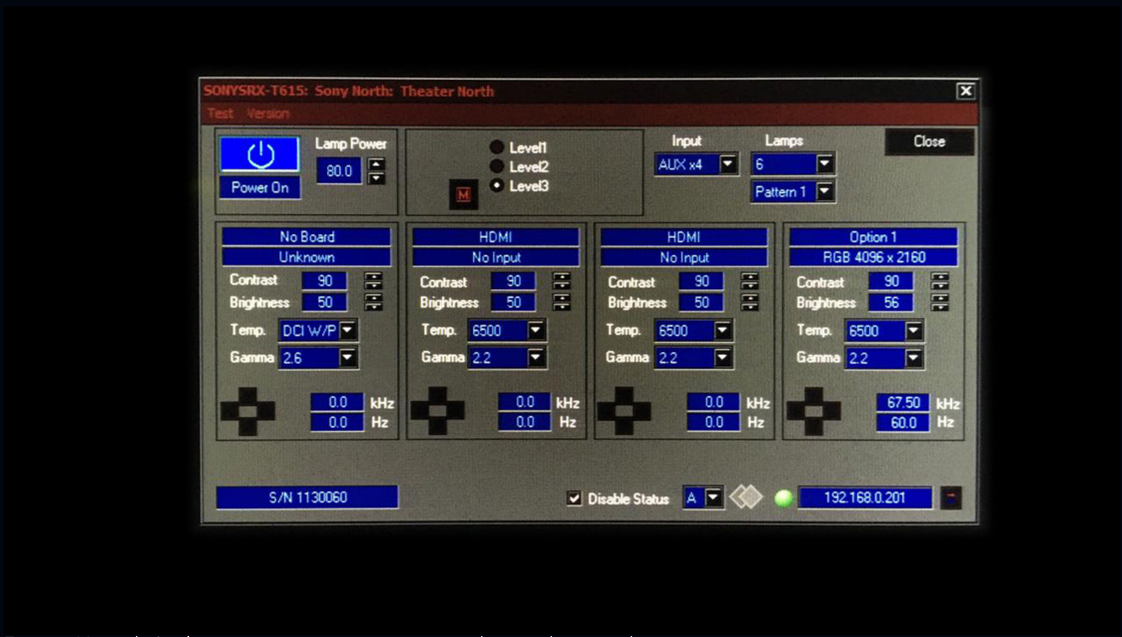
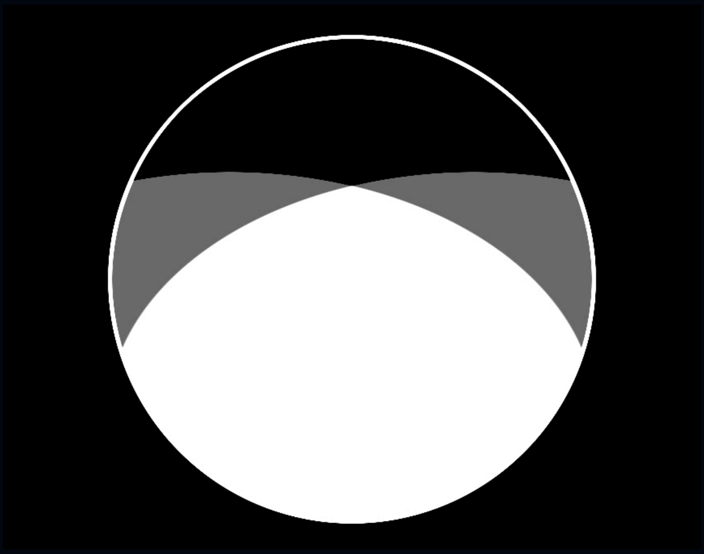


Fig. 11. Heureka's planetarium projector settings during the test shoot.

```
void draw() {
 noStroke();
 //fill(255,255,255,255);
 //rect(0,0,width,height/2);


 //back circle
 fill(0,0,255);
 circle(width/2,height/3-height/40,width/4);

 //front circle
 fill(0,0,0);
 circle(width/2,height/3*2+height/40,width/4);

 //aiming grid
  stroke(127);
  line(0,height/2,width,height/2);
  line(width/2,0,width/2,height);

  stroke(255);
  line(width/2,(height/3)*2,width/2,(height/3)*2+(height/20));
  line(width/2-width/40,(height/3)*2+height/40,width/2+width/40,(height/3)*2+height/40);

  fill(0,0,0,0);
  stroke(127);
  strokeWeight(1);
  circle(width/2,height/2,width);
  circle(width/2,height/3*2+height/40,width/3);
  circle(width/2,height/3*2+height/40,width/4);
```

Fig. 12. Example code for producing the cross-reflection measurement test images (Processing).



2.3 HUMAN VISUAL SYSTEM AND THE DOME

2.3 HUMAN VISUAL SYSTEM AND THE DOME

2.3.1 HUMAN VISUAL FIELD

There are two basic characteristics of the human visual system that are relevant to the decisions made in the production of *"The Embrace of the Ocean"*: the span of the visual field, and the way our vision adapts to low light levels.

Because the human visual field is not wide enough to see the whole planetarium at one glance (Grogorick et al. 2018), and because the unidirectional seating arrangement in Heureka's planetarium and the 23 degree tilt angle of its dome persuade the audience to look into a certain direction, it can be argued that not all of the pixels projected on the dome are equally important. Furthermore, audience gaze can be directed by showing them visual stimuli, i.e. bright or moving visual elements (Grogorick et al. 2018).

If we could reliably expect to know the area of the dome the audience is looking at at any given moment, and if we knew the shape and span of the typical human visual field, we could prioritize certain areas of the dome when planning visual content, and attempt to reduce cross-reflection with minimal inconvenience to the audience.

2.3.2 SWEET SPOT IN HEUREKA'S PLANETARIUM

To determine which pixels on the dome should be prioritized when color grading for reduced cross-reflection, we needed to know where the audience is likely to look, and which parts of the dome they would not often see.

A sweet spot, a location on the screen which the audience can comfortably look at, was estimated by Heureka's AV Producer Lauri Hynninen, who works as part of the team running the daily operations at Heureka's planetarium. In reality, the optimal sweet spot will depend on the location of the seat the viewer occupies, but the framed area estimated by Hynninen was used as a rough composition guide during the film's production.

As a side note: the human visual system is better at sensing color information near the center of vision. Close to the far periphery, color vision is almost non-existent. (Taylor 1973, 652-653) The effect may be significant enough to consider desaturating peripheral dome areas in an effort to eliminate some cross-reflection in some cases. However, for the *"Embrace of the Ocean"* shots were not color graded with the desaturation of peripheral dome areas in mind.

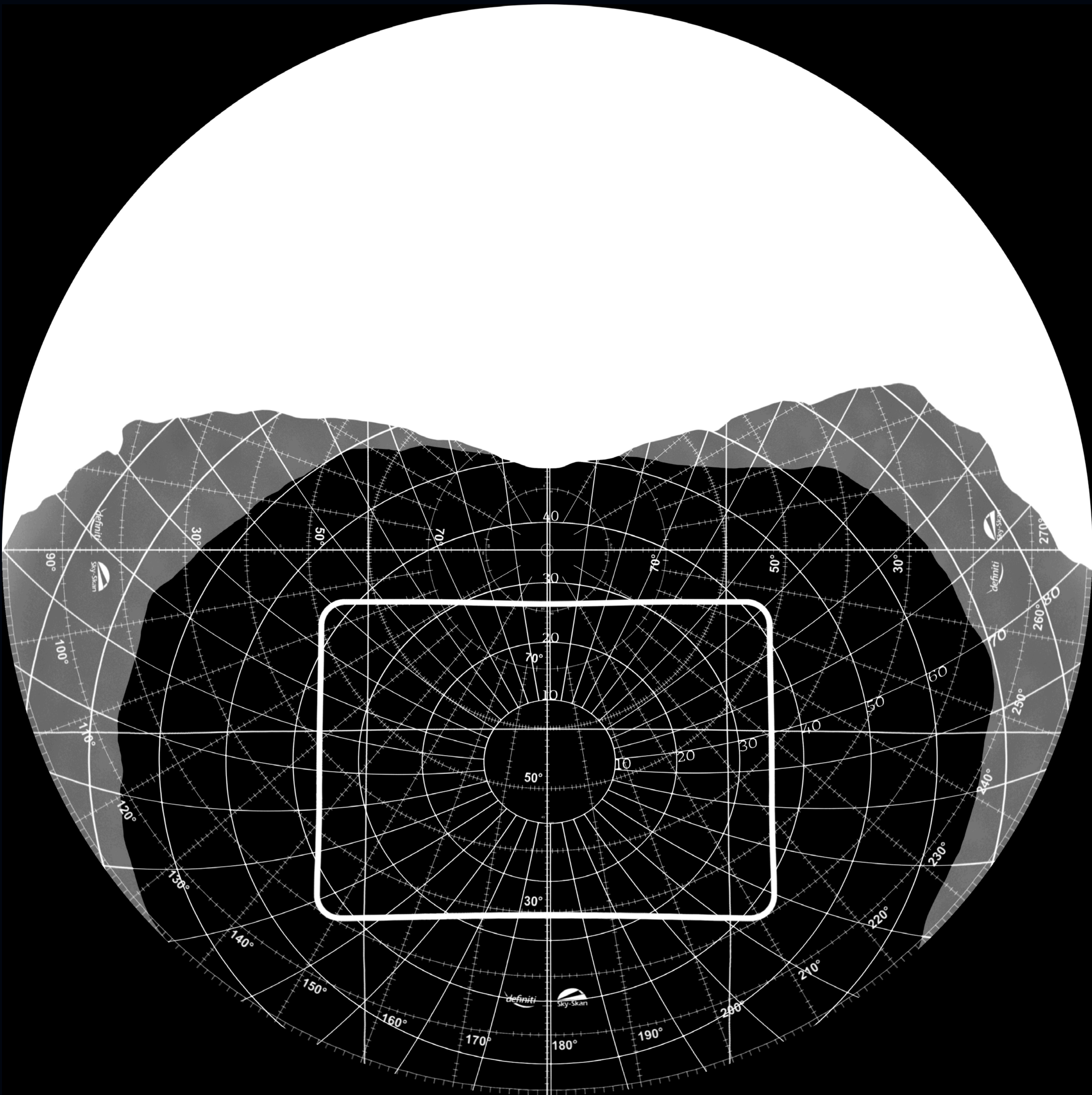


Fig. 13.

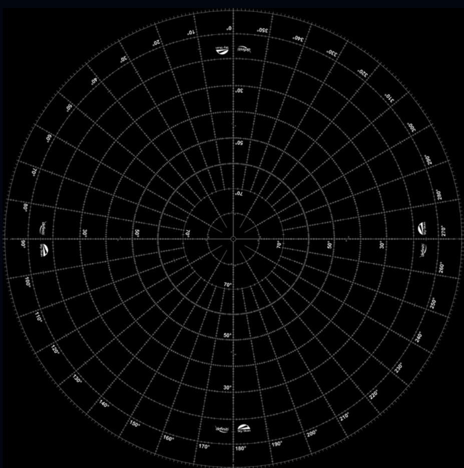


Fig. 14.

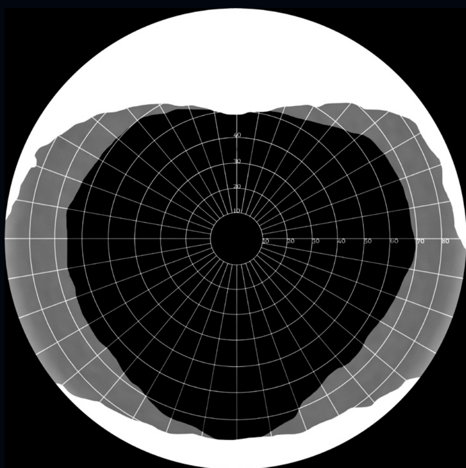


Fig. 15.

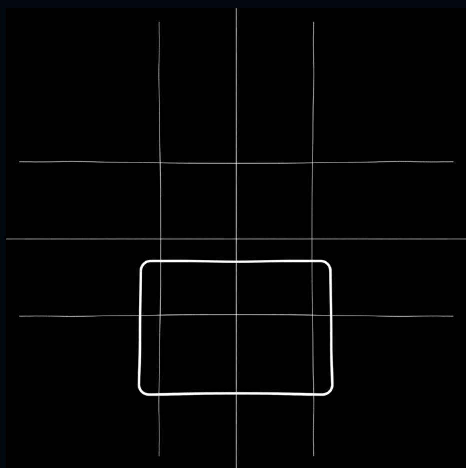


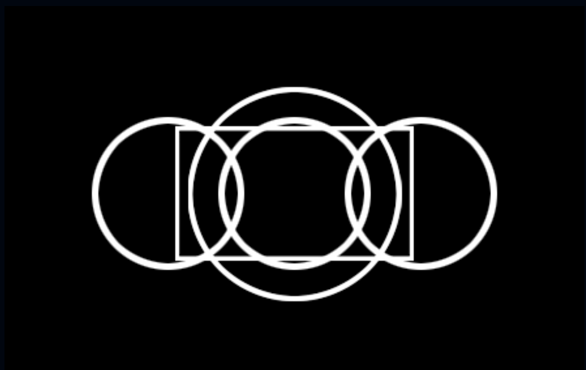
Fig. 16.

Fig. 13. Human visual field, with center of vision aimed at the center of the dome hotspot (-35 degrees from the zenith), superimposed on the Sky-Skan Infiniti grid and the hemispherical composition guide.

Fig. 14. Sky-Skan Infiniti grid from Heureka's planetarium.

Fig. 15. The span of human visual field, (after Bioastronautics Data Book, second edition, NASA, 1973).

Fig. 16. A rectangular marker for determining dome sweet spot location and size in the dome by Lauri Hynninen.



3 SHOT TYPES OF THE EMBRACE OF THE OCEAN

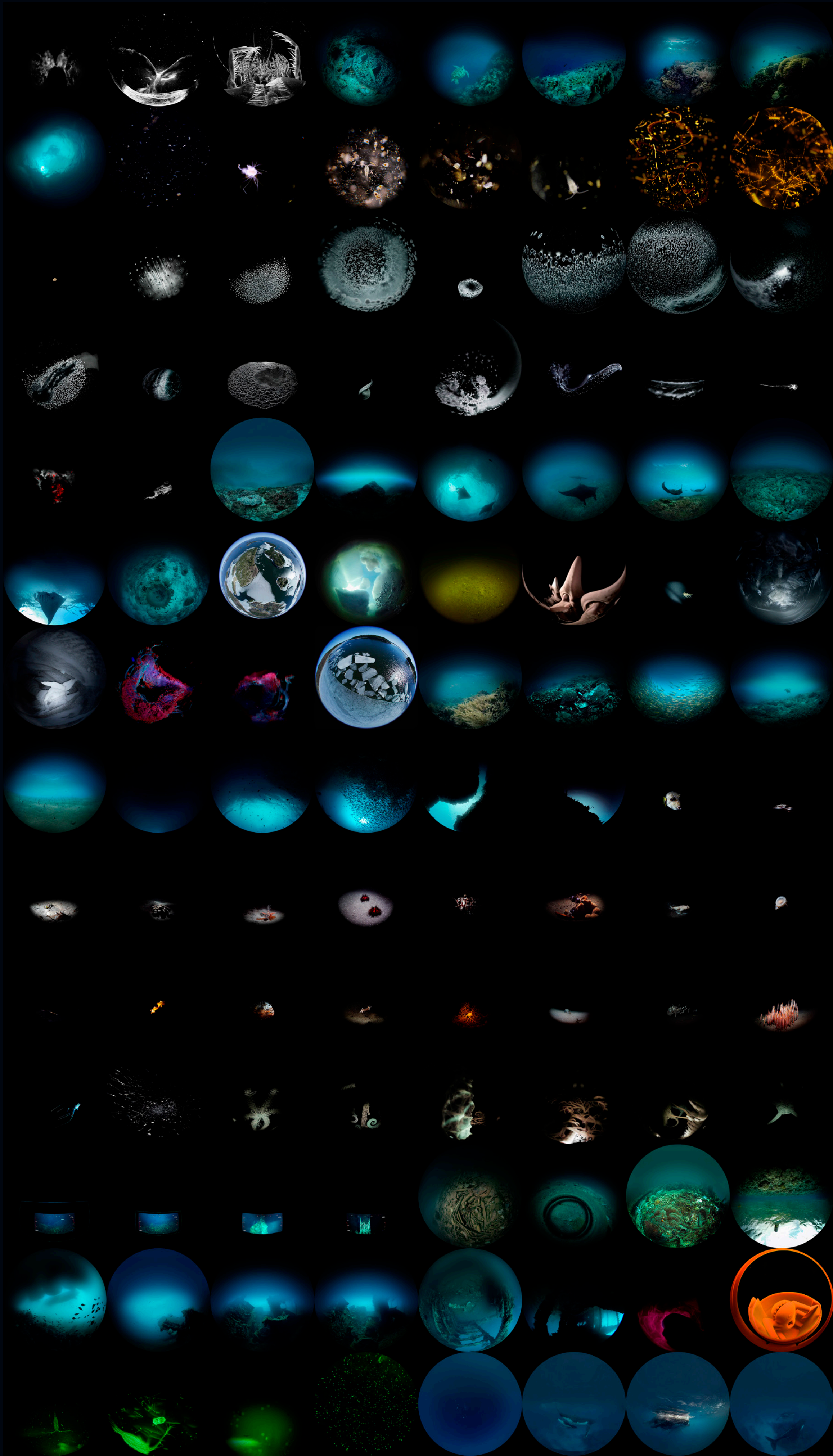


Fig. 17. *"The Embrace of the Ocean"* as a series of still frames.

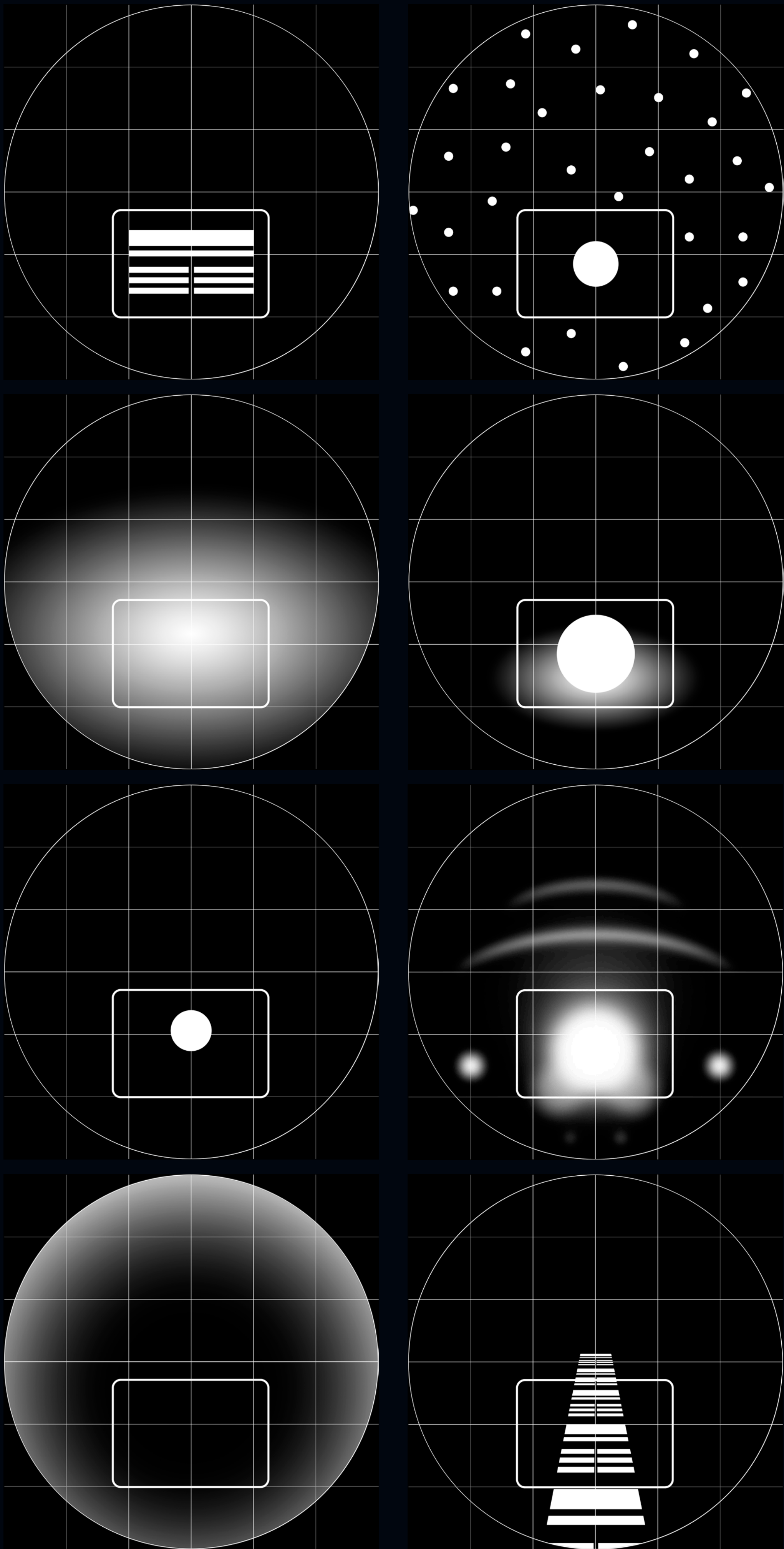


Fig. 18. *"The Embrace of the Ocean"* broken down to 8 basic shot types.

3.1 OPENING TITLES AND END CREDITS

3 SHOT TYPES OF THE EMBRACE OF THE OCEAN

3.1 OPENING TITLES AND END CREDITS

The opening credit sequence was designed so that the audience would have maximum time to have their vision adjust to the relatively low level of illumination prevalent inside the planetarium. The complete dark adaptation of the human eye takes between 30 to 60 minutes in total darkness.

The adaptation is rapid for the first few minutes, then plateaus briefly at the 10-minute mark, then continues again, first rapidly and then plateauing out during the next 20 minutes or so. (Taylor 1973, 654). Lauri Hynninen, an AV Producer at Heureka's planetarium estimated that the audience coming to see a fulldome show spends on average only 1-2 minutes in the relatively low-light conditions of the planetarium before the show begins. The minimalistic design of the opening titles of "*The Embrace of the Ocean*" gives the audience a further 2 minutes more time to adapt their eyes before the first daylight shot of the film appears on screen. According to Taylor, this makes a significant difference in dark adaptation, although the audience will only have properly adapted to the prevailing light conditions close to halfway mark of the film. Coincidentally, this is where the film's night scene begins.

The overall design of the credit sequence is minimalistic white text on a black background, with black and white, almost abstract visualizations of volumetric marine data shown between the credits. To create the look for the opening credits, the volumetric datasets were rendered resembling a glass type material, giving a see-through look with extremely bright highlights. An extremely shallow depth-of-field was simulated to make the datasets almost inrecognizable.

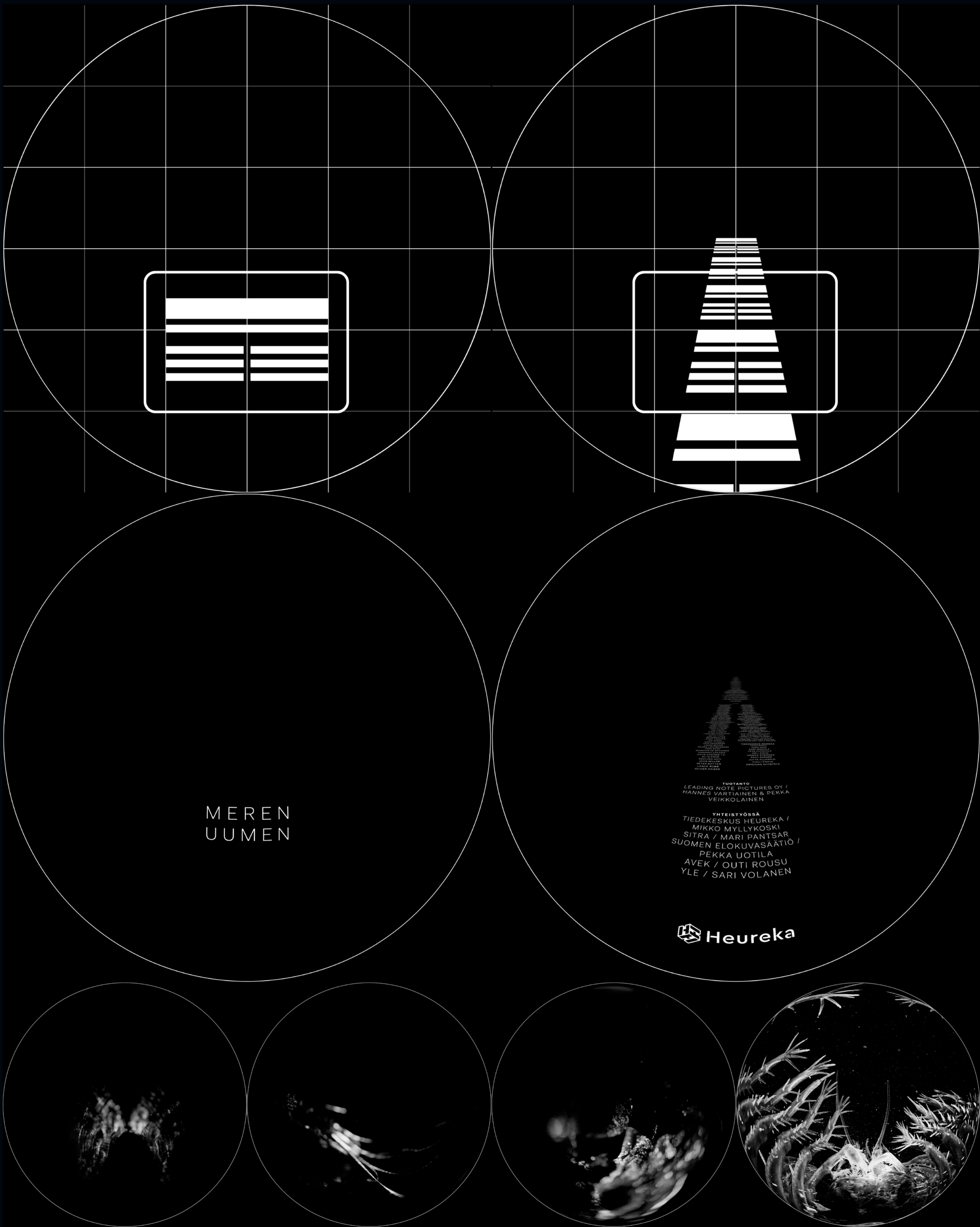


Fig. 19. The opening and ending of *"The Embrace of the Ocean"*. Opening title and end credit design: Otto Donner.

3.2 360-DEGREE UNDERWATER FOOTAGE

3.2 360-DEGREE UNDERWATER FOOTAGE

When considering camera options for creating an underwater nature documentary, one must choose carefully.

We explored options ranging from a single-camera to 6-camera rigs, each with their own advantages and challenges. There were not many options on the market for a single camera that would film at least hemispherical footage and at least at the required 4096x4096 pixel resolution, and none fell within the range allowed by our budget.

The solution was then going to be one of the multi-camera rigs that require "stitching" the different images together in post-production to form a composite image that covers the dome. A multi-camera system comes with its own set of challenges: using a rig with several cameras increases the possibility of one of the cameras failing at a critical moment. Chance for human error such as forgetting to change a memory card or simply forgetting to charge/change batteries in any one of the individual cameras will also increase. We knew the working days will be long and physically demanding during principal photography, so reducing the possibility for error was one of the factors in deciding on camera equipment. Less cameras also means less digital seams to worry about when combining the footage in post-production. This means saving work, and having less problems with synchronizing the footage, matching camera exposure, white balance or any other camera setting.

We decided to use a rig from Boxfish Research Ltd. called Boxfish 360. Inside a sturdy housing there are 3 4K cameras, each set up vertically. The system is somewhat automated, so that all the cameras are charged through one single charging cable and when recording, the cameras are synchronized by the pressing of a single record button. The system also creates pre-stitched template files for quick previewing of the footage, a significant time-saver when previewing and classifying the material in post-production.

The setbacks of Boxfish 360 are that the cameras record compressed video files instead of RAW files and that once the cameras are turned on on the surface and the housing is closed and sealed, there is no way to adjust any camera settings, such as aperture or exposure. This meant that we had to plan each dive very carefully and set the manual exposure to a specific range of depths at which we were to film, no matter what was encountered underwater; filming much deeper would mean underexposed shots, filming closer to the surface would mean overexposure.

The advantage of using the Boxfish 360, but only needing one half of the omnidirectional footage the rig creates, was that the main forward-pointing camera alone was usually enough to cover most of the dome, while the backwards-facing cameras 2 and 3 were often used to cover the peripheral areas of the dome. Because of this, any problems while stitching the footage would be hard to spot, as the seams would be situated at the very edge areas of the dome and often covered by the same masking and color-grading steps that would be taken anyway to reduce cross-reflection. Not having to worry about stitching quality on most of the seams sped up the post-production workflow considerably.

Recording with a 360 camera rig also offered more options in the post-production phase. Filming conditions were sometimes challenging due to water currents or proximity to surface waves or waves crashing against the shoreline. Provided that other divers were situated directly behind the cinematographer, it was usually possible to re-orient the camera angle in Adobe After Effects to better frame the subjects even from sub-optimal (shaky, partially over-exposed, misaligned) footage. In some cases it was also possible to track a subject matter with a camera pan created completely in post-production, something that was very challenging to do in a controlled manner while underwater.

One of the persistent problems of filming with the Boxfish in daylight was that often when the frontal camera was pointed at a subject, the brightest area of the surrounding environment, the sky above the water surface, would be visible in the image. When stitching the camera footage, the bright sunlit sky would fall on the back half of the dome, behind the audience's back, and the darker ocean and ocean bottom would fill the sweet spot of the dome.

This problem was tackled in different ways. First, diving almost weightlessly in the water makes it possible to swim in any which direction, and a lot of the marine life don't live a life of being stuck on flat horizontal plane like us humans are. This freedom of movement was often used to reduce the amount of sky visible, and in some cases the shots were even turned upside down, darkening the back of the dome and bringing the bright sky element to the sweet spot.

In some cases I completely replaced the bright sunlit water surface at the back of the dome with a darker, context-appropriate color. The reason for this was the challenging combination of filming near the water's surface where sunlight still penetrates water well. At the depth of just a few meters colors, especially red, were still vivid, but the back of the dome tended to get flooded with bright or overexposed pixels.

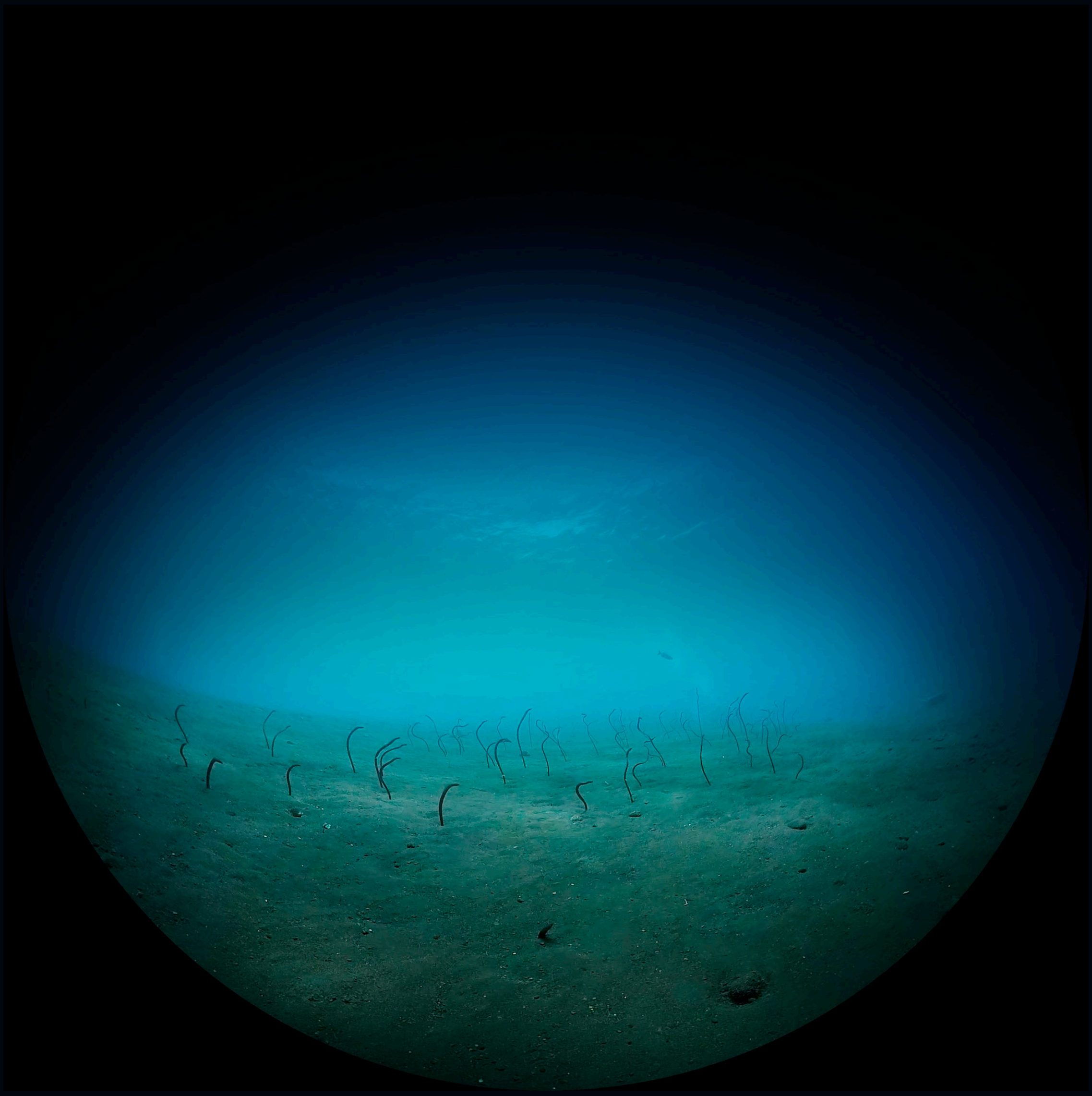


Fig. 20. Boxfish 360 in action over a field of garden eels.


Fig. 21. Cinematographer Anna Kekkonen diving the USS Liberty wreck with the Boxfish 360.

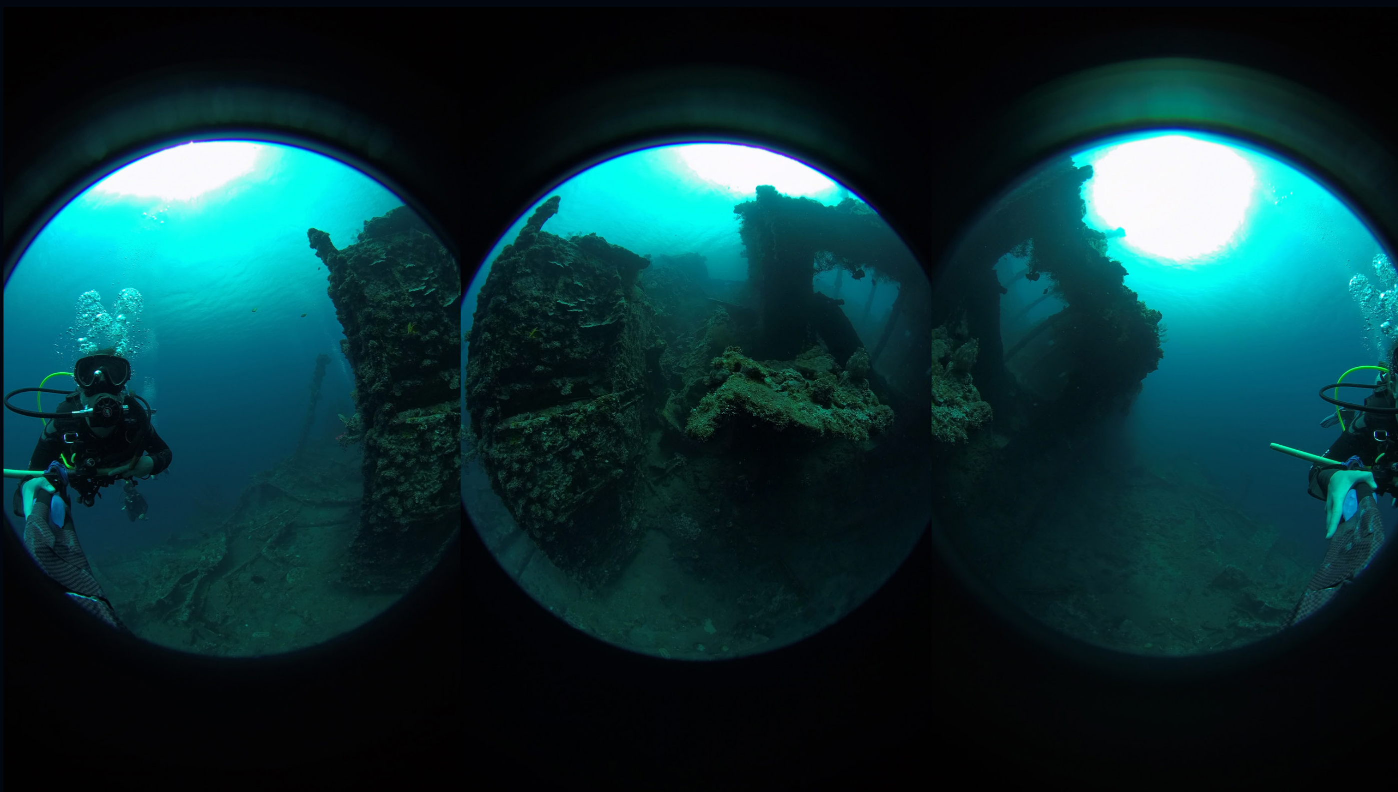


Fig. 22. Boxfish 360 rig consists of 3 synchronized 4K cameras.

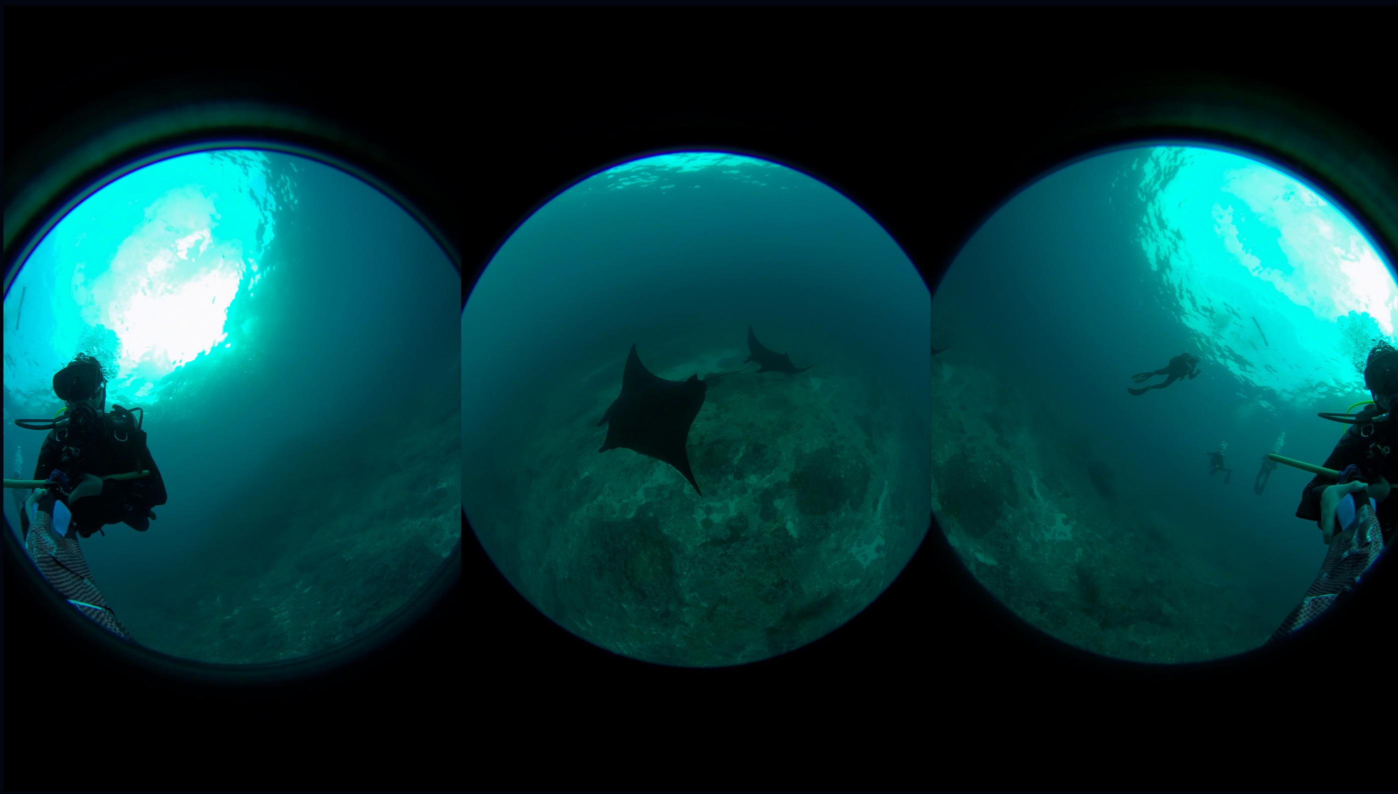


Fig. 23. A still frame from each of the 3 cameras of the Boxfish 360.


Fig. 24. Still frames combined into an equirectangular 2:1 projection in Kolor Autopano Video 3.0.

Fig. 25. The equirectangular projection reprojected as a Fisheye (Fulldome) projection in Adobe After Effects CC.

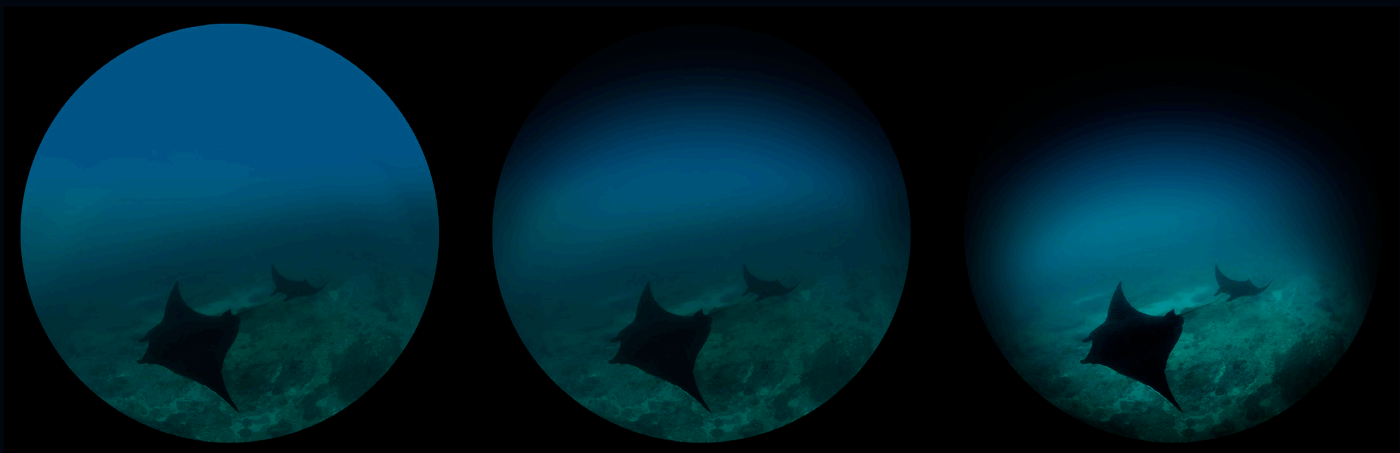


Fig. 26. Masking, darkening and improving contrast in Adobe After Effects CC.

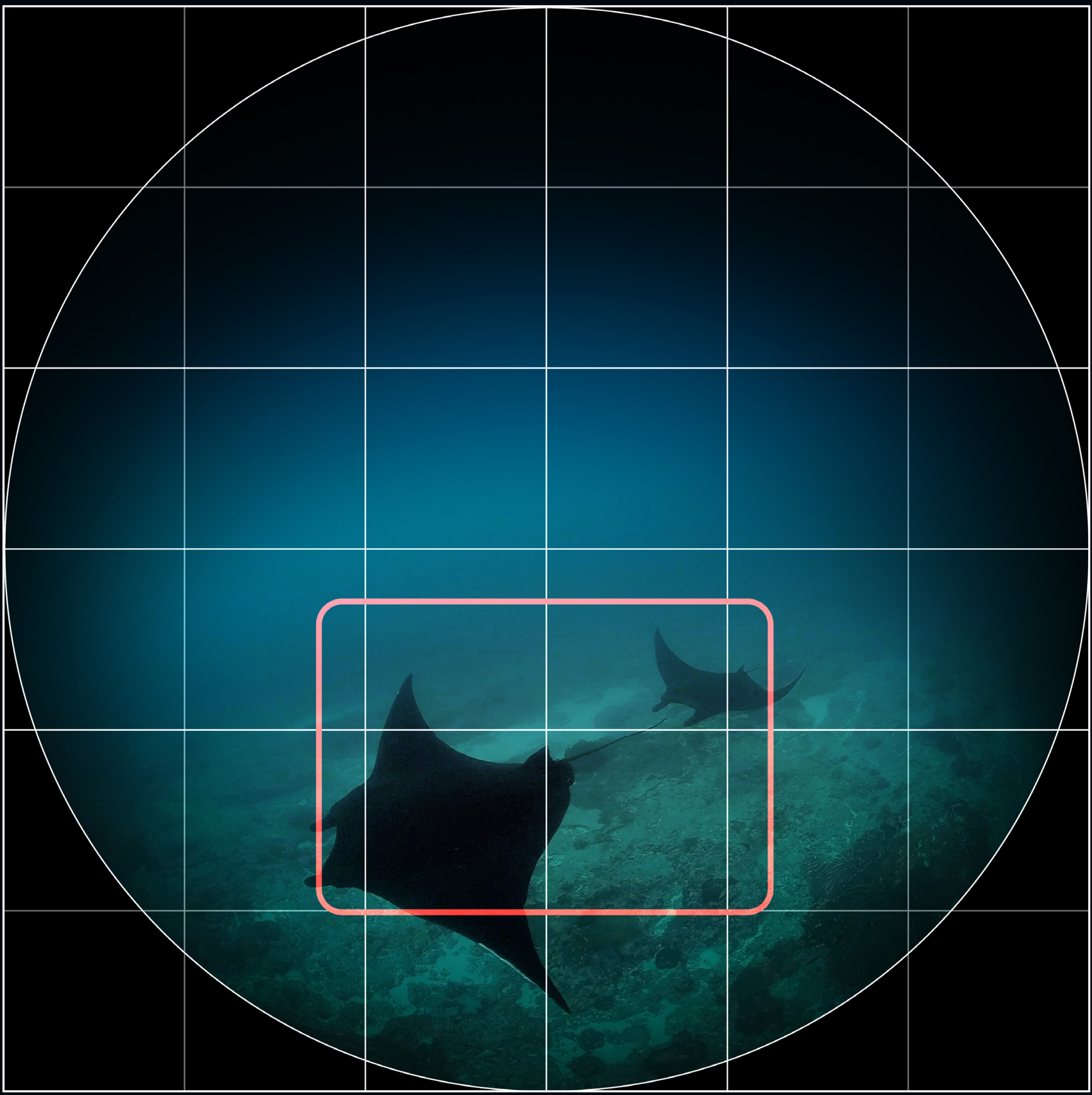


Fig. 27. Final color graded hemispherical frame ready to be rendered in Adobe After Effects CC.

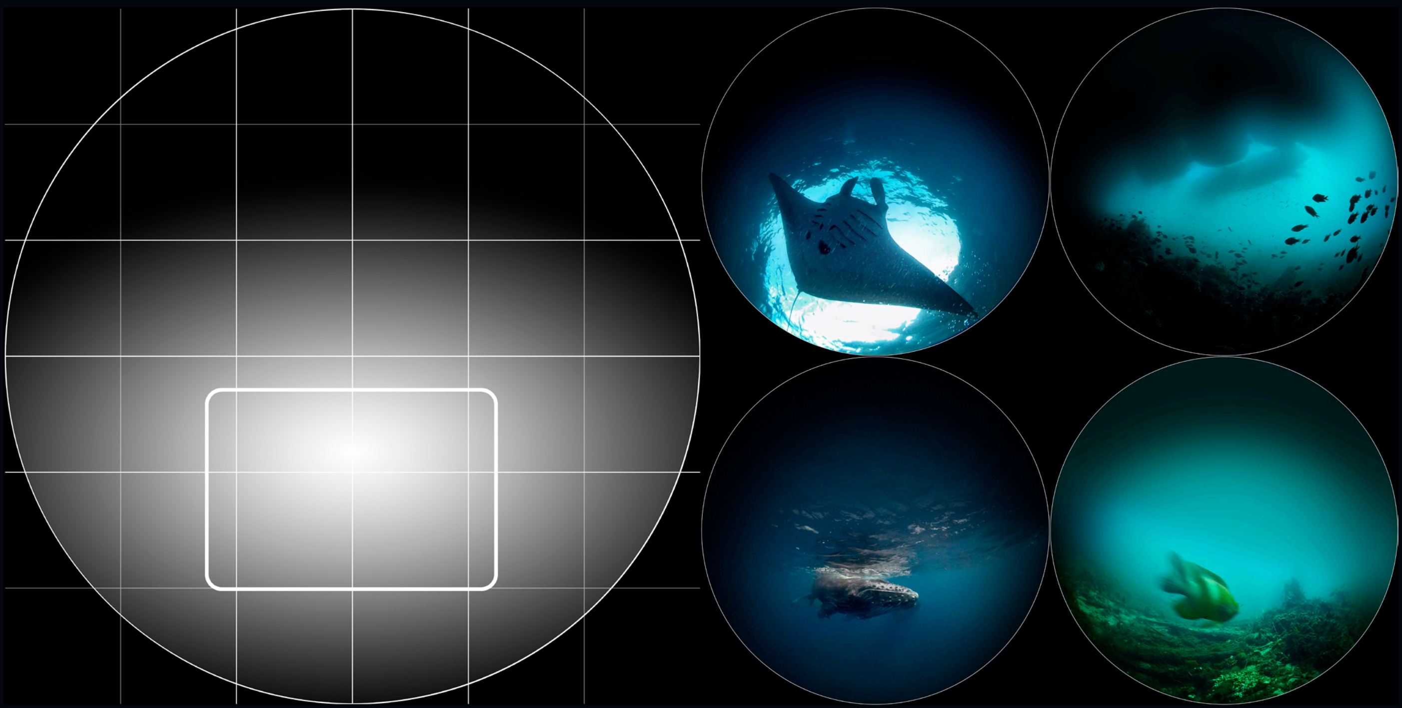


Fig. 28. A series of hemispherical still frames from *"The Embrace of the Ocean"*.

3.3 UNDERWATER FOOTAGE WITH SONY A7 III

3.3 UNDERWATER FOOTAGE WITH SONY A7 III

While the Boxfish 360 provided us with images that could fill the whole dome and thus surround the audience wholly, we also needed a solution for getting closeup shots of various underwater subjects. Fisheye lenses do not have zoom capabilities, so to get a closeup shot the camera must be moved very close to the subject, sometimes just millimeters away. While filming a nature documentary it is often not possible to get that up and close to the subject matter, or it can be dangerous to the subjects or the equipment and the film crew.

For principal photography, we decided on a Sony a7 III, with a Zeiss Vario-Tessar 16-35 mm lens secured in a Nauticam NA-A7RII underwater housing. This setup will not produce any footage suitable for filling the dome as is. However, we planned a part of the film to be shot at night, and in tandem with spotlights we could create carefully lit shots that would illuminate only the sweet spot, leaving the rest of the dome in darkness and the audience none the wiser about the camera switch.

In practice it was difficult to control the spotlight beam perfectly underwater. Providing that the cinematography and lighting were executed successfully, further digital editing was used to complete the spotlight fall-off into pitch-black before it reached the image edge was done in post-production.

The end result is bright, high contrast and vivid images of nocturnal animals, with minimal cross-reflection. Shown against a black background the footage blends seamlessly to the black areas of the dome, making the rectangular edges of the original video footage disappear completely.

As an introduction to the night scene in the film, the audience is shown Boxfish 360 footage of the night arriving. This acts as an establishing shot, and is designed to disguise the fact that the following shots are not natively suitable for the dome. While the narrator comments on the weird creatures that inhabit the ocean, it gets completely dark in the dome. All subsequent shots of the ocean night are shots produced with the Sony a7 III.

Fig. 29. A Blue swimmer crab at Wori muck-diving site in North Sulawesi, Indonesia. Photo credit: Petra Laurinen.

Fig. 30. A still frame from Sony a7 III of a nocturnal, demersal fish (Uranoscopus sulphureus).

Fig. 31. Digital masking of video edges in Adobe After Effects CC.

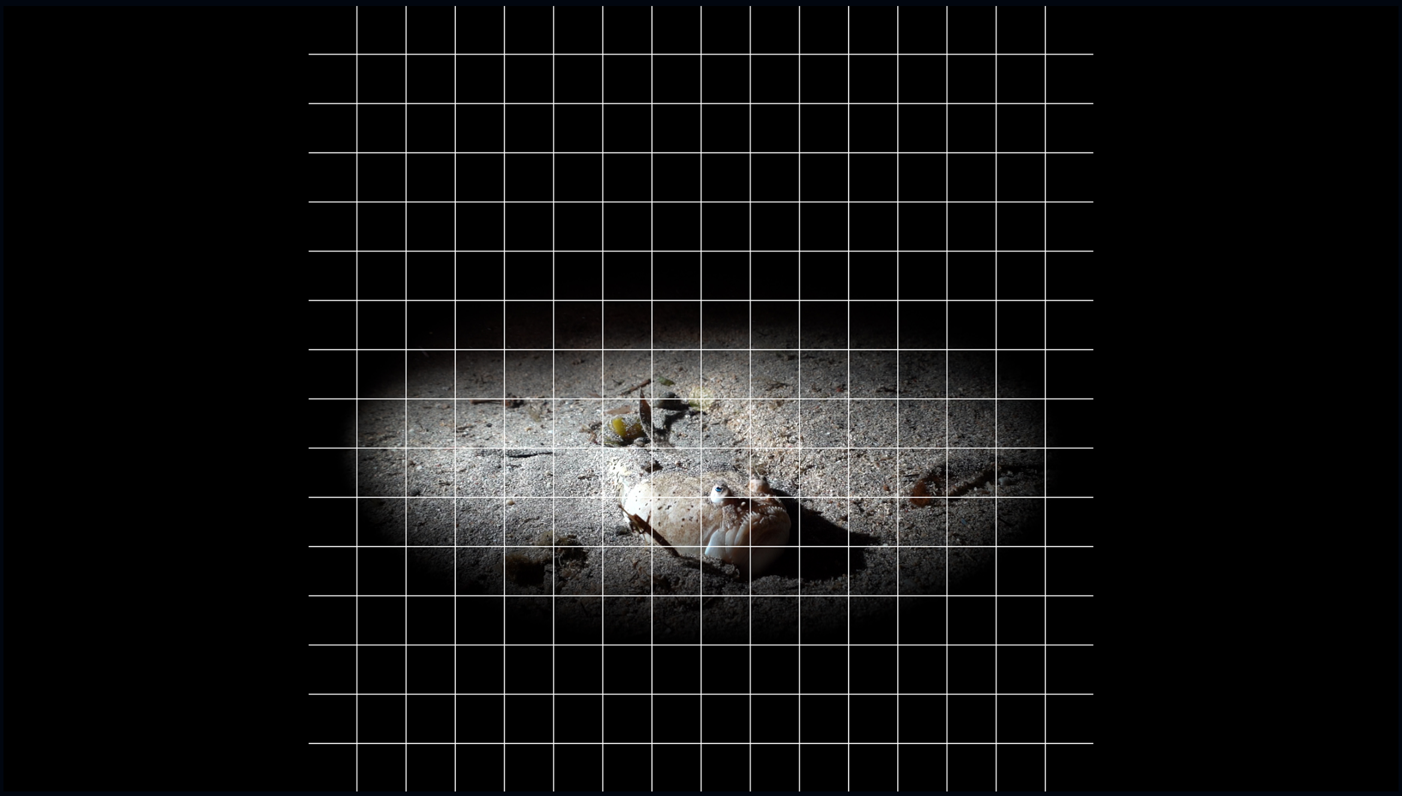


Fig. 32. Masked video set up for composing and dome distortion in Adobe After Effects CC.

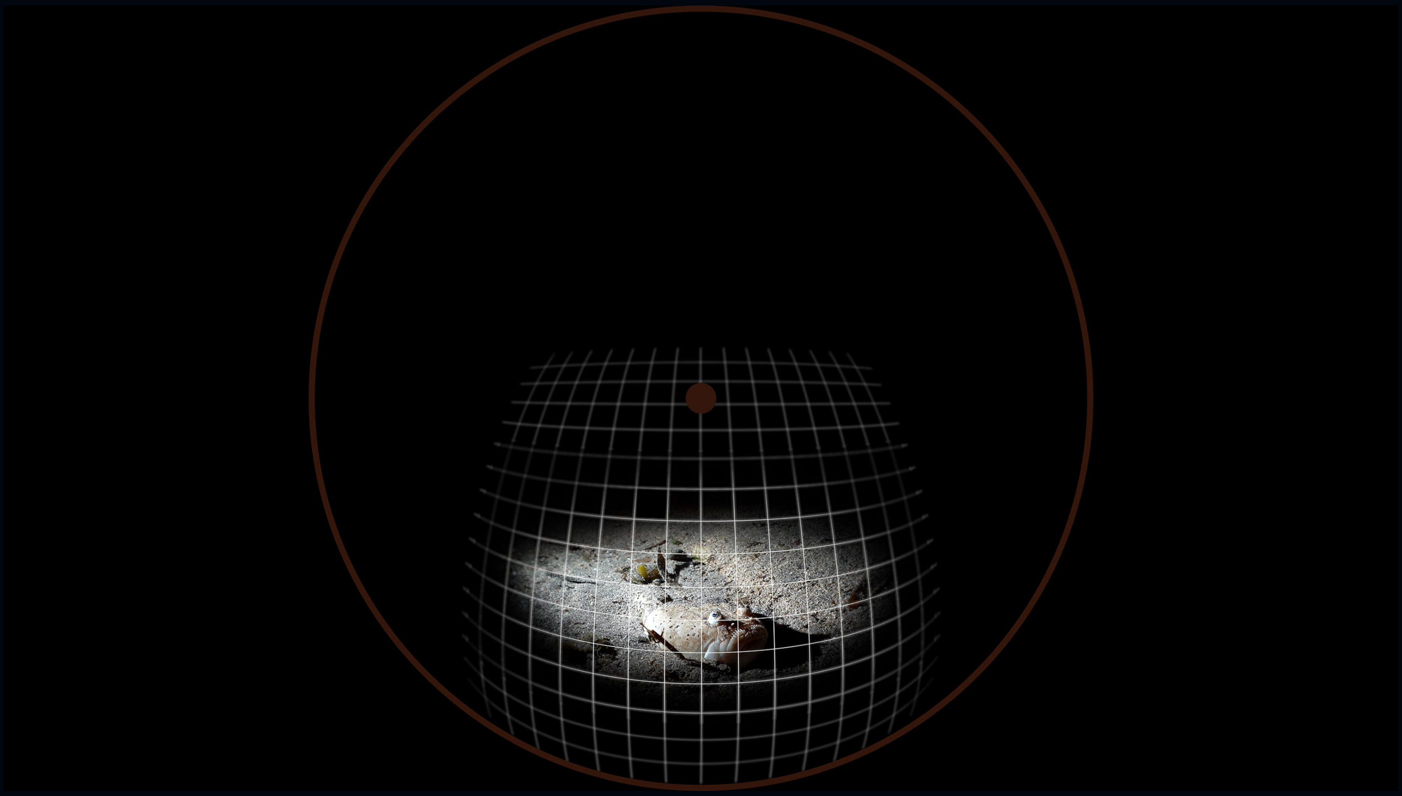


Fig. 33. A color-corrected, composed frame ready to be rendered in Dome Master format.

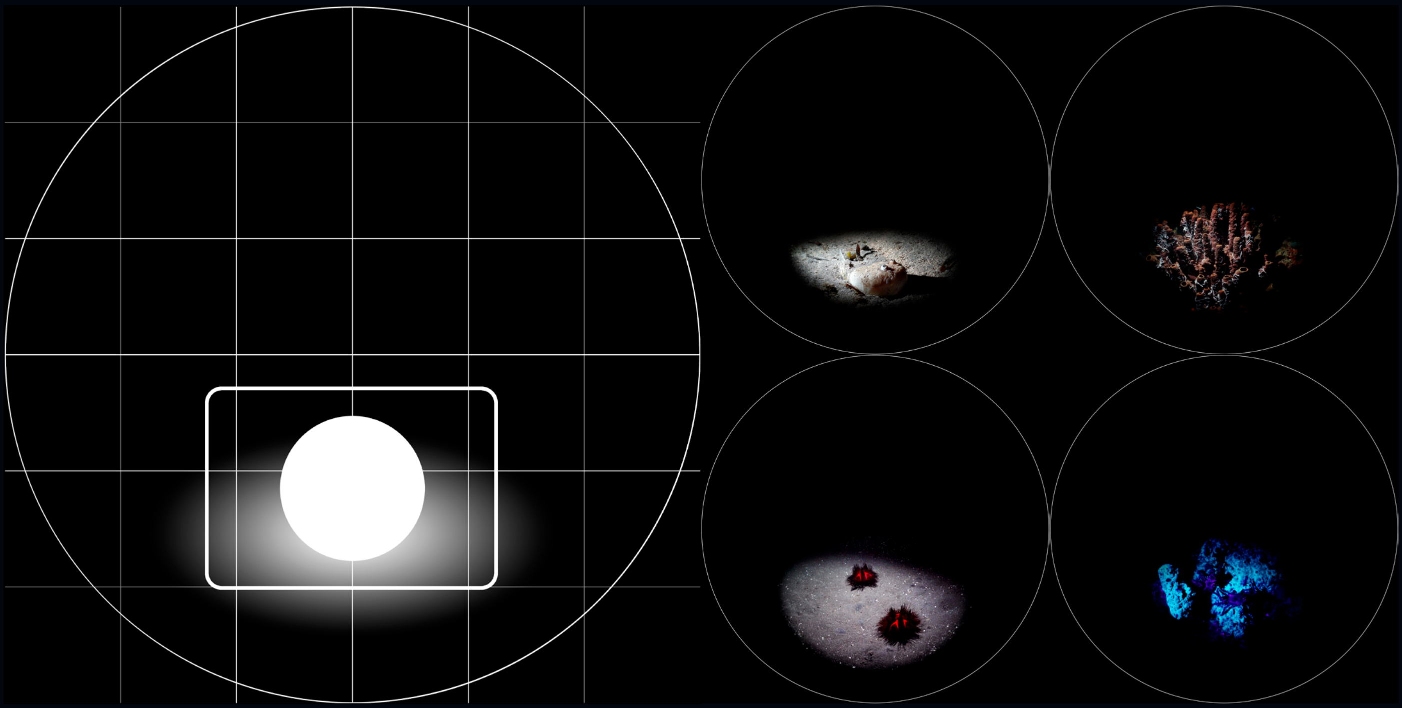


Fig. 34. A series of Sony a7 III still frames from *"The Embrace of the Ocean"* shot against sea floor.

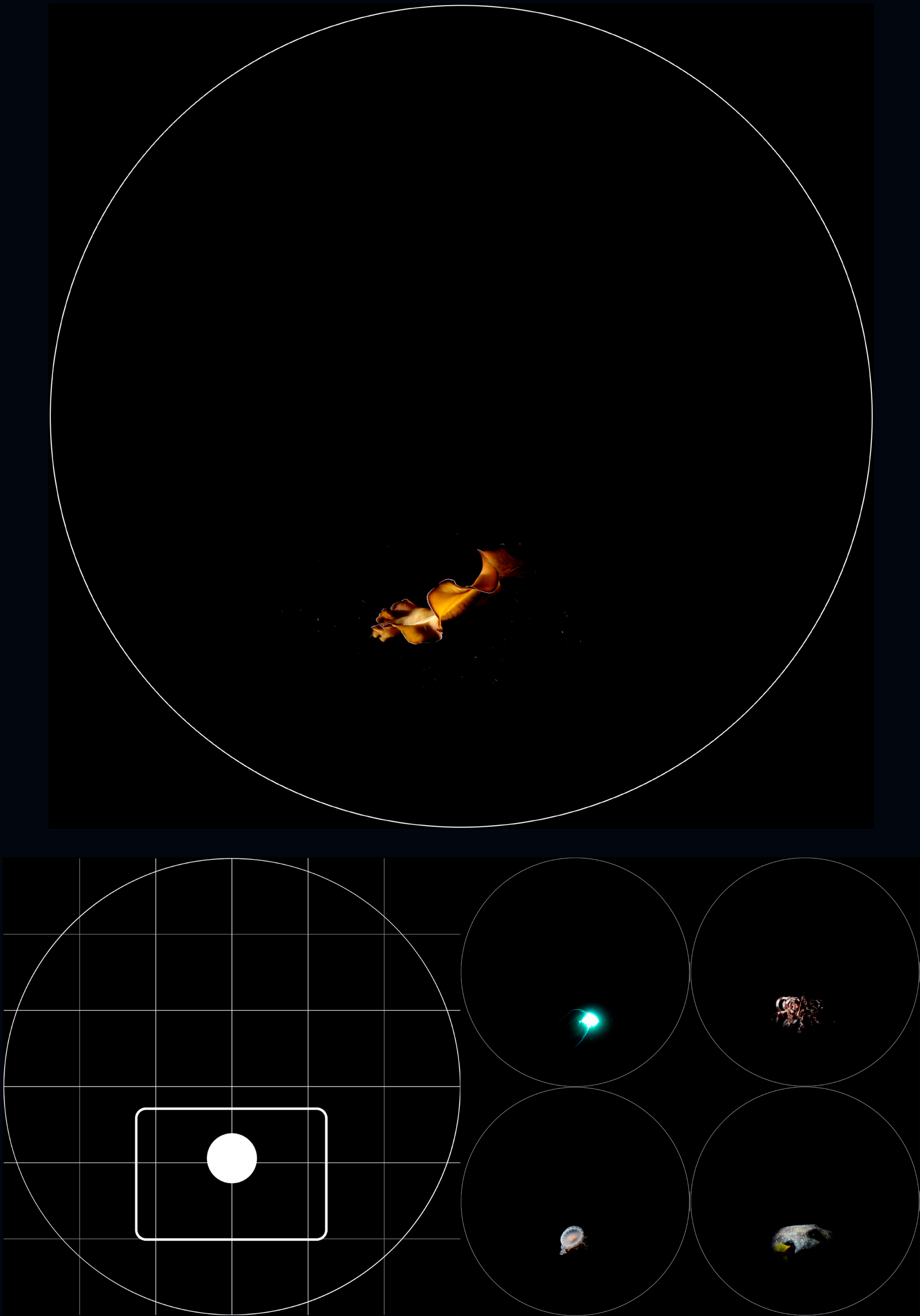


Fig. 35. A series of Sony a7 III still frames from *"The Embrace of the Ocean"* shot against a dark ocean background.

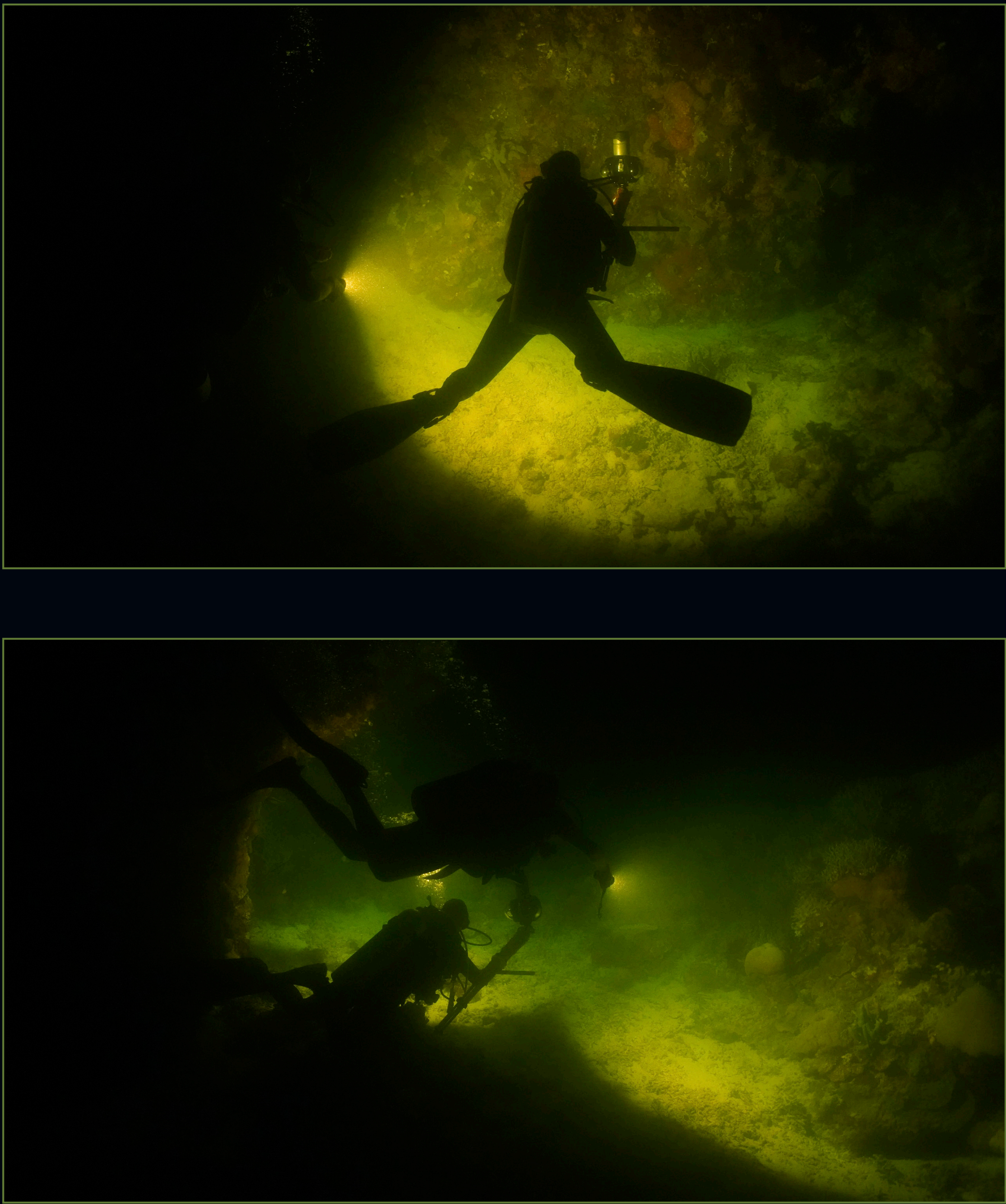
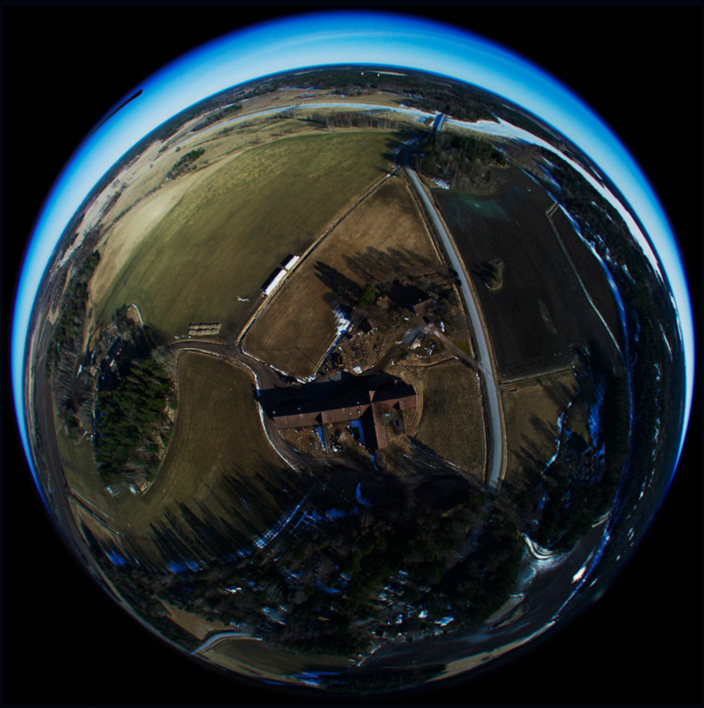


Fig. 36. Night diving with Boxfish 360. Photo credit: Hannes Vartiainen.



3.4 AERIAL FOOTAGE

3.4 AERIAL FOOTAGE

Our previous fulldome production *"The Secret World of Moths"* included several shots representing landscapes in Finland and Uganda. We felt it was necessary to include them as part of the film's structure, but the amount of cross-reflection created by the bright outside visual elements was distracting in the dome.

For *"The Embrace of the Ocean"* we decided to try aerial drone footage, filming from high up in the air directly down towards the water and ground. This mitigated the problem somewhat by not flooding the dome with bright sky behind the audience's visual field, but a common characteristic of the footage was that the brightest areas of any shot fell usually at the very peripheral areas of the dome.

Scaling the aerial footage down to fill the dome only partially was used as an establishing shot to the scene featuring the Baltic sea, making the imagery resemble a miniature planet. Shown first as heavily scaled-down, then slowly expanding to fill the whole dome, the aerial shot changes seamlessly from a bright spot surrounded by a dark dome to a full-blown immersive shot enveloping the audience.

Apart from scaling down the footage to not fill the whole dome, hemispherical daylight landscape shots resist easy ways of controlling crossreflection, and we have decided that including them, problems and all, is a necessary part of the fulldome nature documentary film structure.

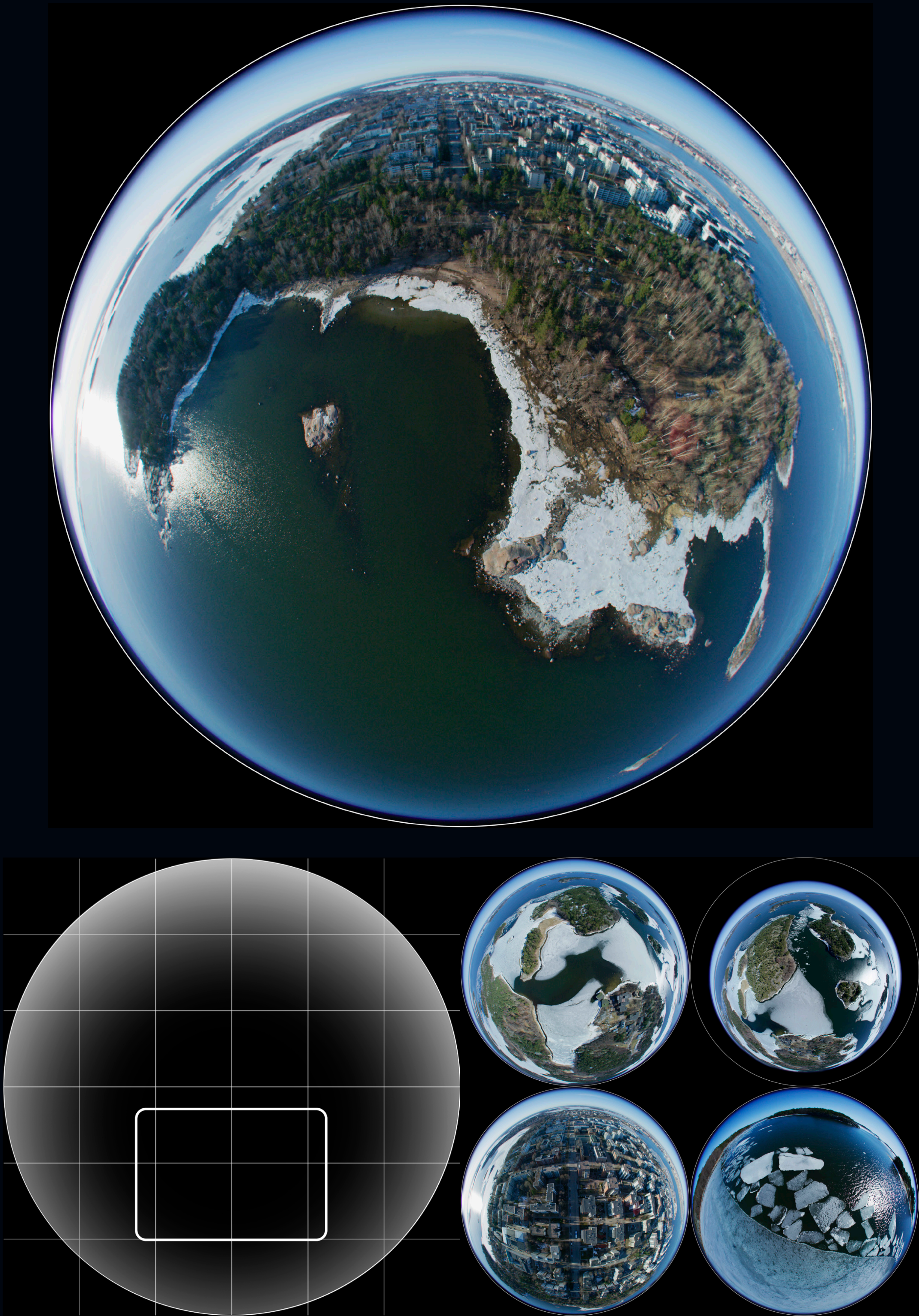


Fig. 37. A series of RED Helium 8K S35 still frames with a Sunex 5.6mm Superfisheye lens. Shot credit: KopterCam.

3.5 DARK-FIELD MICROSCOPY

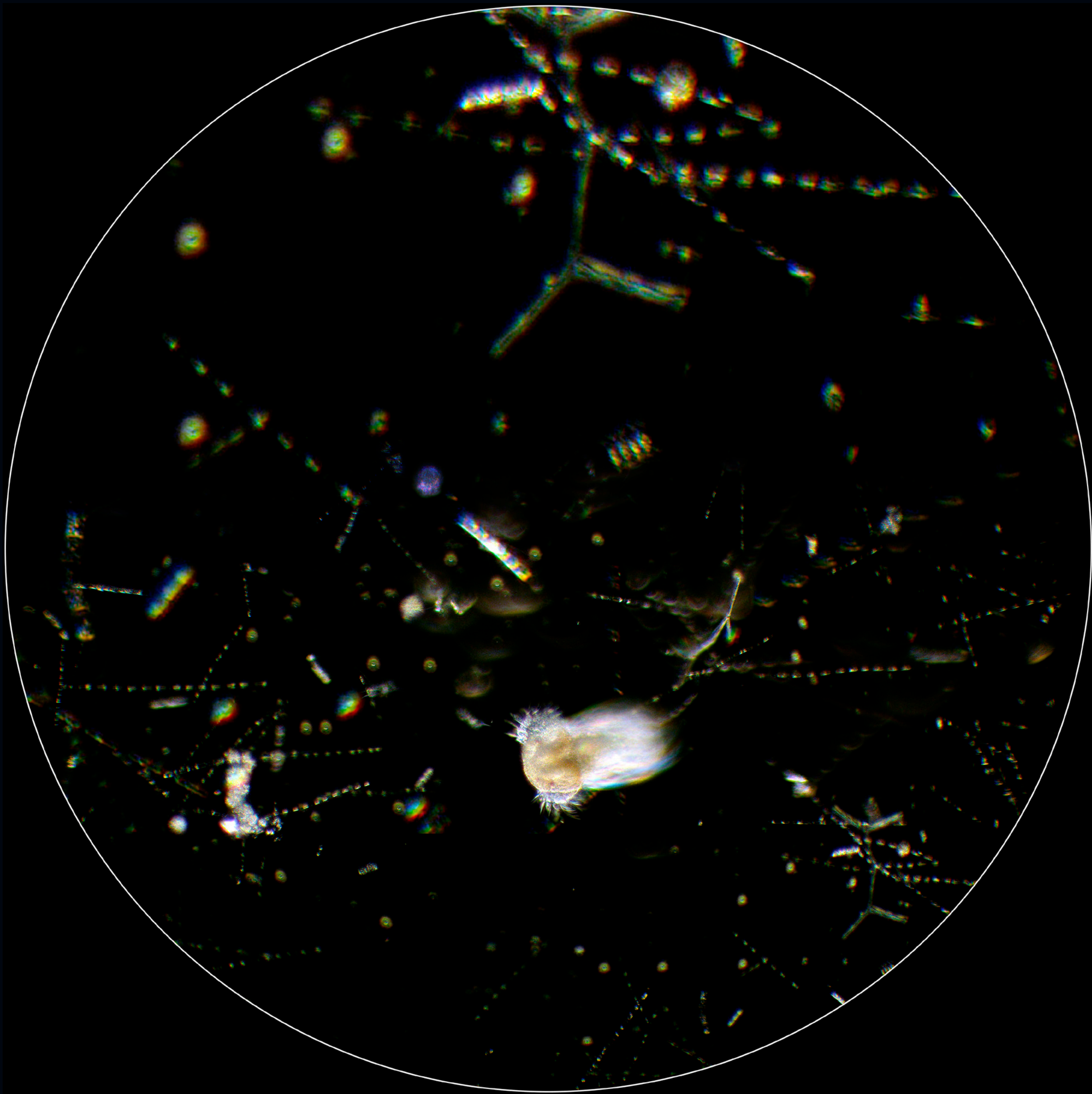
3.5 DARK-FIELD MICROSCOPY

One of the major scenes in the film features sea plankton. Filming plankton with a fisheye lens is not possible to the best of my knowledge. It is, however, quite straight-forward with a digital camera connected to the right kind of microscope. The film's planktonscapes were created at Tvärminne Zoological Station, who provided us with facilities and samples. We brought our own camera and an adapter to mount it on their microscope.

Dark-field microscopy provided us footage of bright planktonic organisms against a dark background. Even though the footage of the plankton swimming in a petri dish was not shot in hemispherical format, the characteristics of the microscope itself provided interesting circular cropping and in some cases some heavy chromatic aberration that was used to fit the footage to the dome.

Due to the outlandish look of the phytoplankton and zooplankton and their relatively small size on the dome as individual elements, I decided not to warp the images at all as I would do to other non-hemispherical footage, but instead treat the plankton as if they were constellations in the night sky, and build compositions and fill the dome that way.

The Red Epic connected to the microscope records footage at various high resolutions and frame rates up to 5K width, but it cannot fill the entire 4K Dome Master vertically. However, the nature of the plankton footage allowed for easy compositing. Combining several shots together also serves to show the audience the various types of common plankton in the sea in less time and give the audience reason to have their gaze wander around the dome, if they so choose.



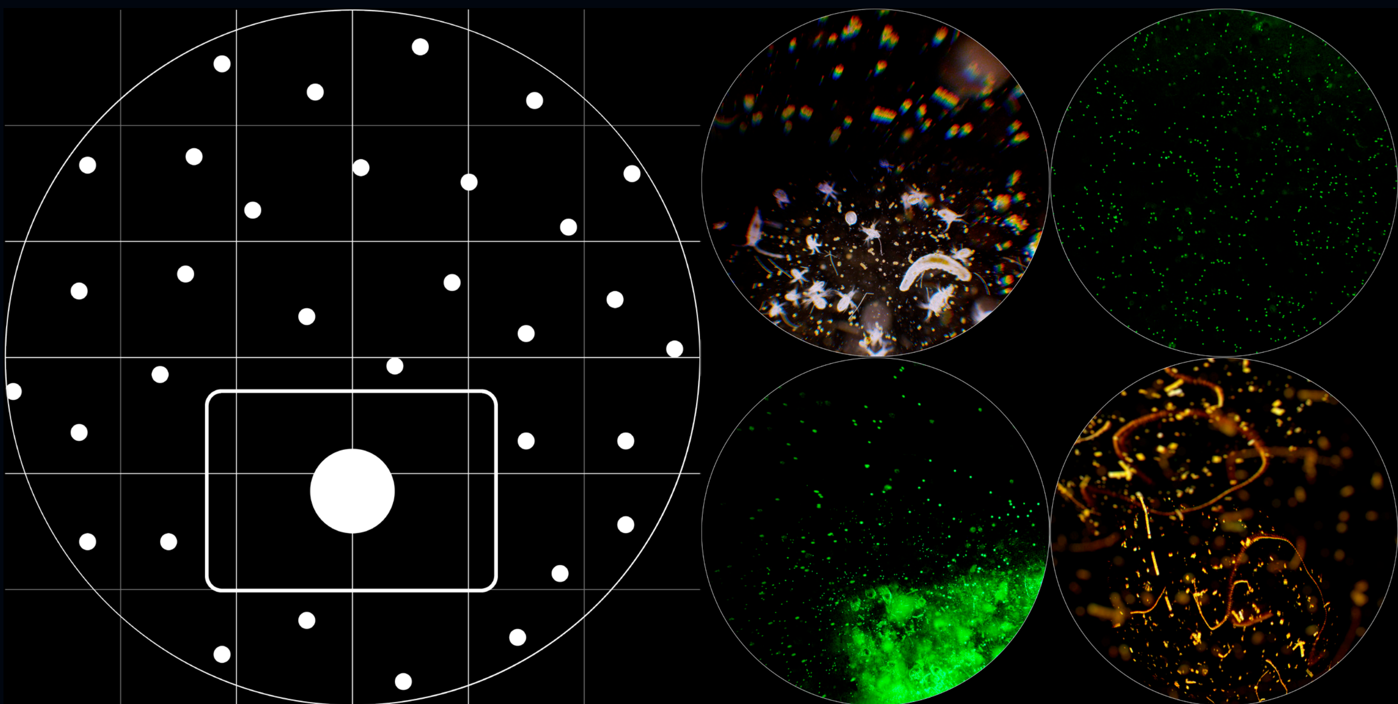


Fig. 38. A series of composite shots of Baltic sea plankton, shot with Red Epic Mysterium-X and a Leica DMIRB microscope. Samples and facilities: Tvärminne Zoological Station / Hanna Halonen and the Finnish Environment Institute / Pinja Näkki.

3.6 VOLUMETRIC DATA VISUALIZATION

3.6 VOLUMETRIC DATA VISUALIZATION

Volumetric data visualization and the fulldome format are an interesting combination for a filmmaker. *"The Embrace of the Ocean"* utilizes volumetric datasets in several parts of the film to visualize subject matters in ways that would be impossible using traditional cameras.

Our collaboration with Janne Pulkkinen started in 2010 over the mutual interest of visualizing volumetric data. The first results of working together can bee seen in *"The Death of an Insect"* (2010), for which several datasets of insects were produced by Ghent University's Centre for X-ray Tomography. Since then, Janne's volume renderer has developed alongside our film productions and it was also used to create the sequences of volumetric data visualization for *"The Embrace of the Ocean"*. The featured datasets consist of various marine animals and algae from the Baltic sea and other parts of the world, provided by Ghent University and Helsinki University, and of optical tomography datasets based on light microscope data provided by several universities and researchers from around the world.

Regardless of how it was produced, the volumetric datasets we used share a common characteristic: they consist of a stack of two-dimensional images, where each image represents a thin cross-section of the imaged sample. There may be dozens, hundreds or even thousands of cross-sections to a dataset, and there may be a single dataset depicting a subject matter, or there may be a series of datasets showing change over time.

Visualizing these image stacks as blocks of volume elements (voxels) lets us explore the dataset from the inside as well as outside, free from the limitations of any physical camera size. Once a dataset has been produced, it is possible to create near endless variation of visualizations of it by selectively manipulating the color and opacity of the dataset's voxels and the position and properties of virtual cameras and lights inside a virtual environment.

3.6.1 Kilkki *(Saduria entomon)*

3.6.1 KILKKI *(SADURIA ENTOMON)*

Kilkki is a thumb-sized, benthic isopod crustacean living in the Baltic sea, an ice age relic. It lives in abundant numbers on the sea floor and is featured in the film through a variety of shots ranging from live footage from the sea floor to aquarium, confocal microscopy data of kilkki's brain and MicroCT data of the whole kilkki and its insides.

Using a combination of different imaging techniques made it possible to show the animal in its natural habitat (with the Boxfish 360), then film its peculiar swimming technique in slow motion in an aquarium in a controlled studio setting, against a black background (with a Red Epic Mysterium-X).

Due to kilkki being an aquatic animal and relatively small in size, some samples were scanned at Helsinki University MicroCT Laboratory. through the high resolution X-ray microCT scans we were freed from the physical limitations of real-world cameras and thus able to explore the morphology of the animal at an extremely close range, even going inside kilkki and showing her peculiar way of protecting her young: by carrying them inside the mother's brood pouch.

Finally, for an ultimate closeup, the structure of kilkki's brain was revealed to the audience through rendering of volumetric microscopy data provided by Matthes Kenning and Steffen Harzsch from University of Greifswald.

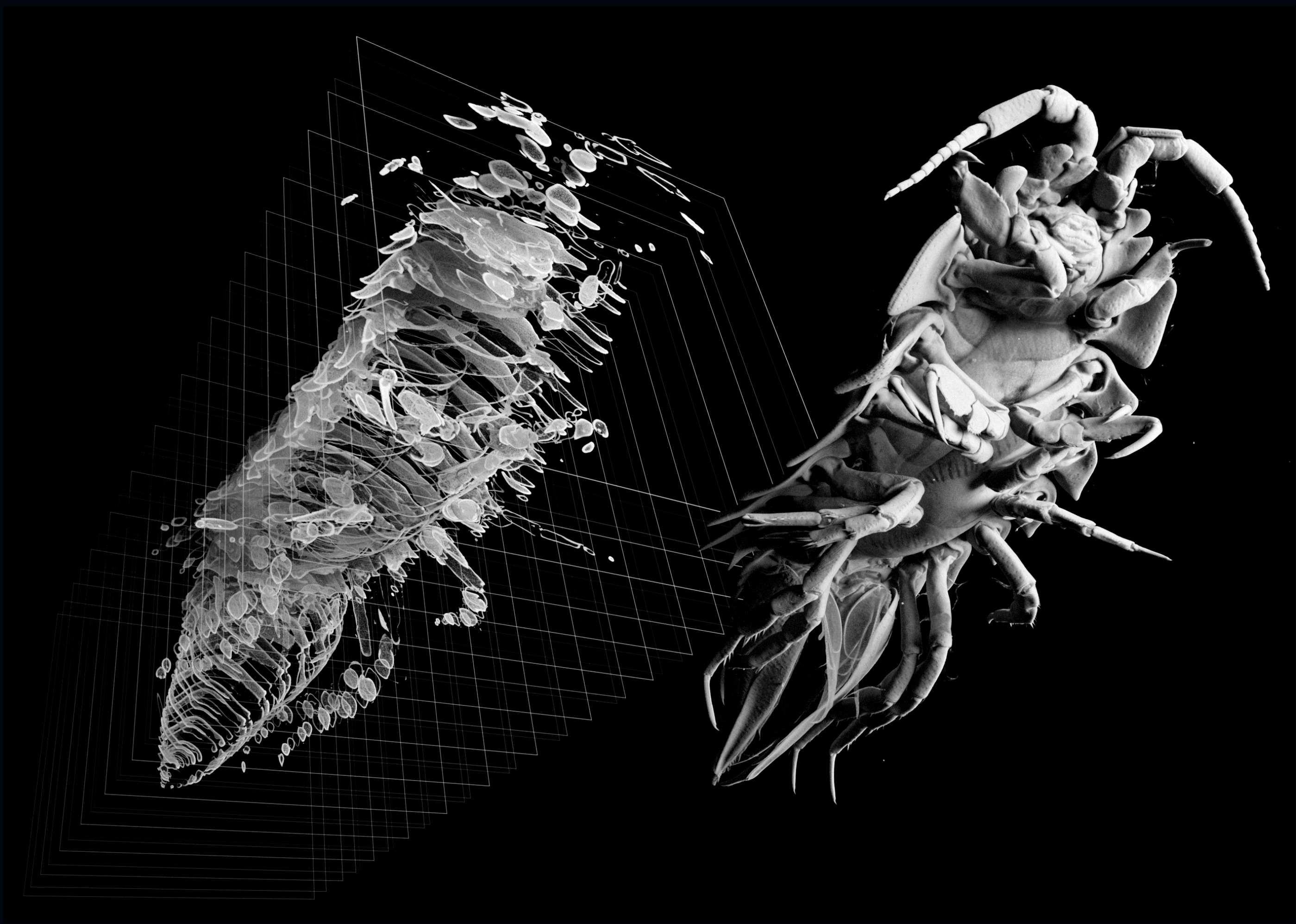


Fig. 39. An example of an X-ray microCT dataset. Dataset credit: University of Helsinki MicroCT Laboratory.

Fig. 40. Saduria entomon, exploration of X-ray microCT dataset visualization possibilities.
Sample acquisition, preparation, dataset credit: University of Helsinki.


Fig. 41. Exploring the insides of S. entomon. Dataset credit: University of Helsinki MicroCT Laboratory. Render: Janne Pulkkinen.


Fig. 42. Exploring the brood pouch of S. entomon. Virtual camera and spotlight revealed juveniles hiding inside the pouch.
Dataset credit: University of Helsinki. Render: Janne Pulkkinen.

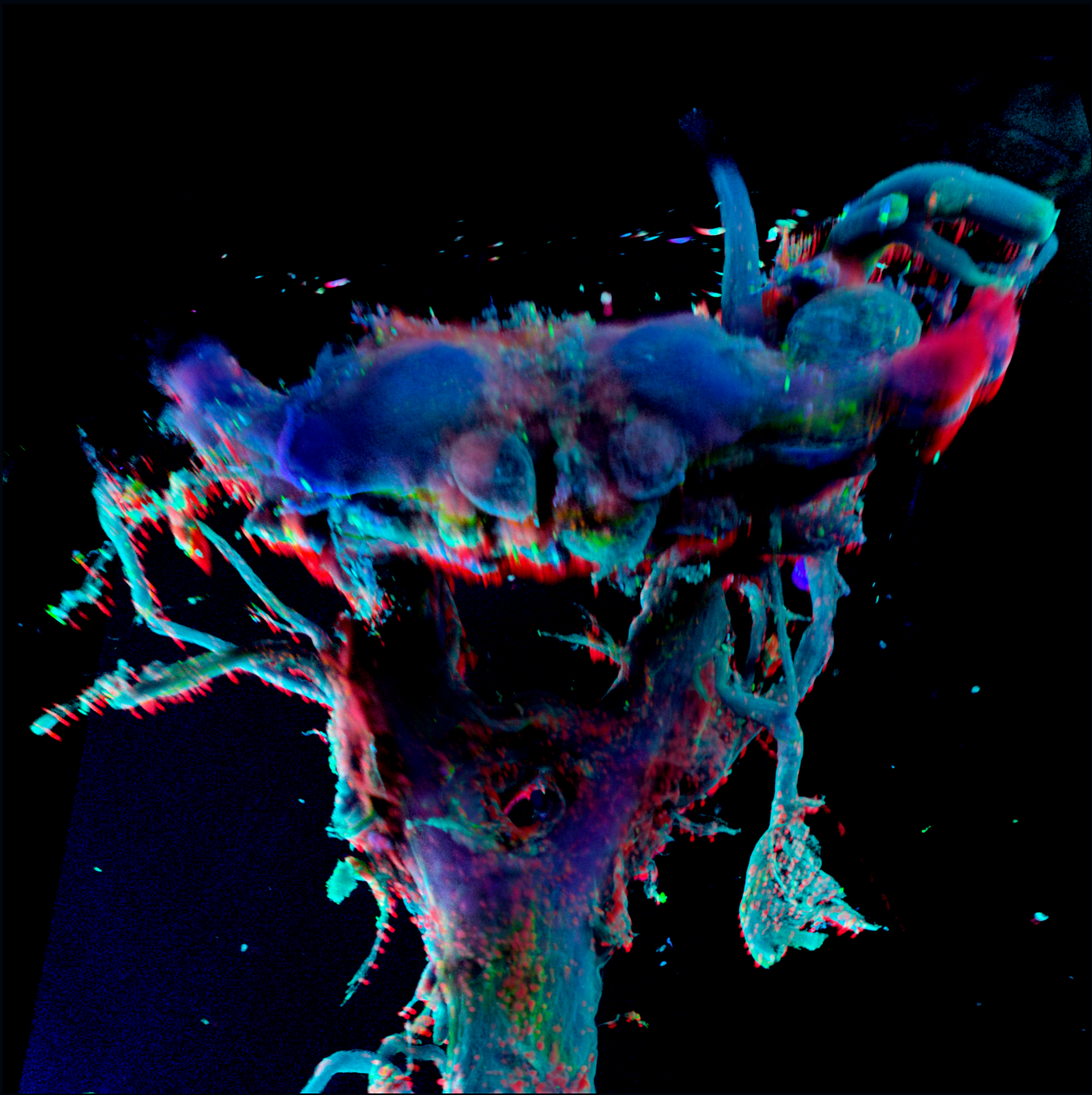
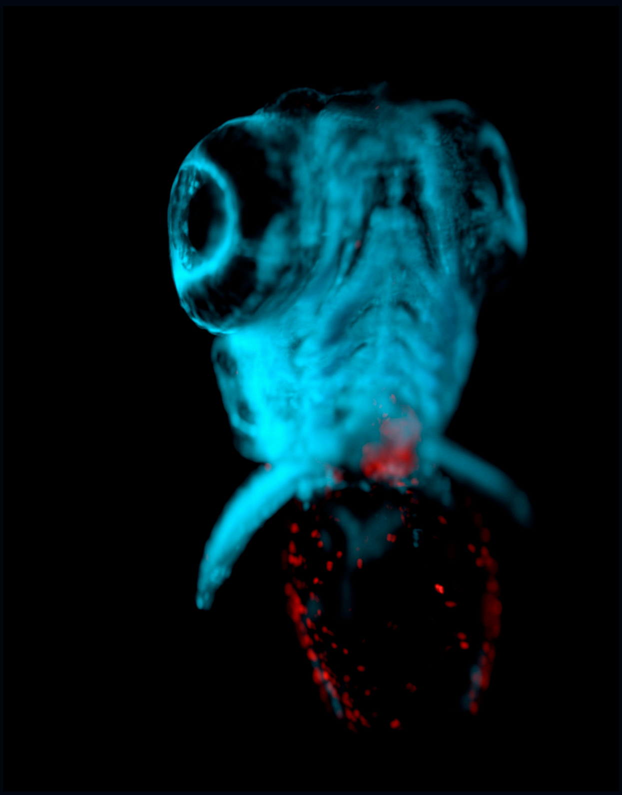


Fig. 43. Saduria entomon brain visualization. Dataset credit: Dr. Matthes Kenning, Prof. Dr. Stephen Harzsch, DFG Ha 2540/9-1.



3.6.2 Zebrafish (*Danio rerio*)

3.6.2 ZEBRAFISH *(DANIO RERIO)*

In one scene of *"The Embrace of the Ocean"* an embryotic zebrafish *(Danio rerio)* develops from a scarce group of cells into a fully grown fish. The scene was realized by rendering out series of datasets based on volumetric microscope data.

Volumetric data of developing zebrafish is produced in various imaging facilities and laboratories around the world. The datasets for *"The Embrace of The Ocean"* were primarily created at the BioVis platform of Uppsala University, Sweden, and the HHMI Janelia Research Campus, Virginia, United States.

These datasets are created by focusing the microscope's camera through the mostly transparent fish embryo while simultaneously capturing a series of images with an extremely narrow depth of field, creating a stack of cross-sectional representations of the embryo. By using genetically modified fish strains and lasers the fish tissues can be highlighted selectively by making some parts of the fish fluoresce while the rest stays transparent.

The challenge for the film production was moving and handling the huge amount of datasets: the visualization of zebrafish development in the film is based on several timelapse series of three-dimensional data, some consisting of more than a thousand timepoints, or invidual datasets. In some cases we worked with the original raw data from the microscopes, where each timepoint was stored in a file several gigabytes in size. The total size of all of the zebrafish data received for the film exceeded 20 terabytes, before the data was converted for rendering. Just storing the raw data itself required a dedicated server and the data required more storage space than all the rest of the film's footage combined, several times over.

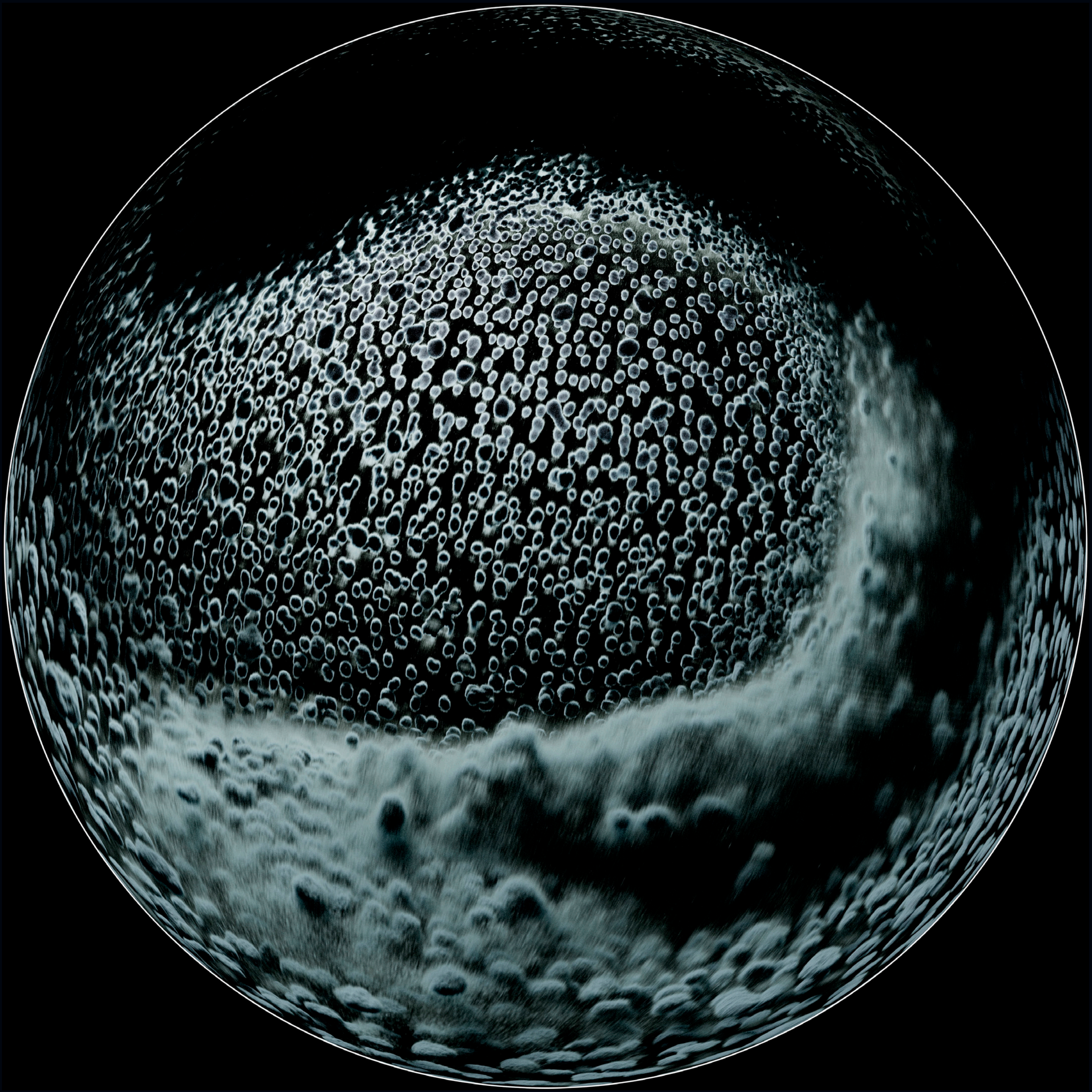


Fig. 44. Zebrafish *(Danio rerio)* developing embryo. Dataset credit: Ph.D. Philipp Keller, HHMI Janelia Research Campus.

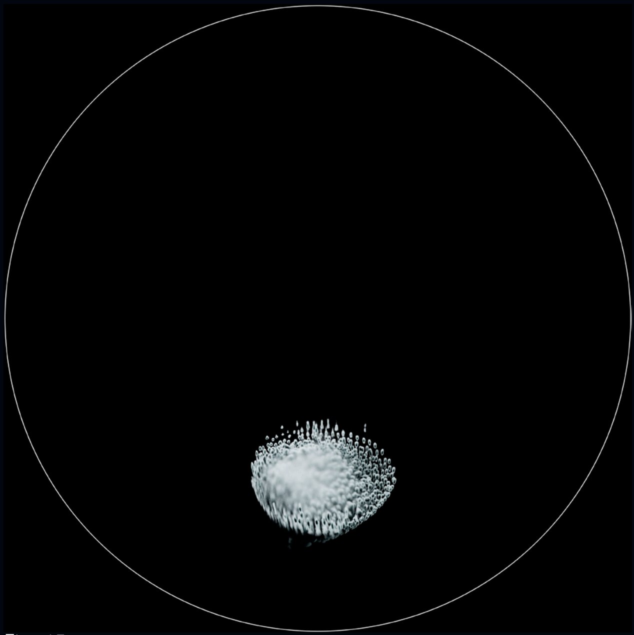


Fig. 45.

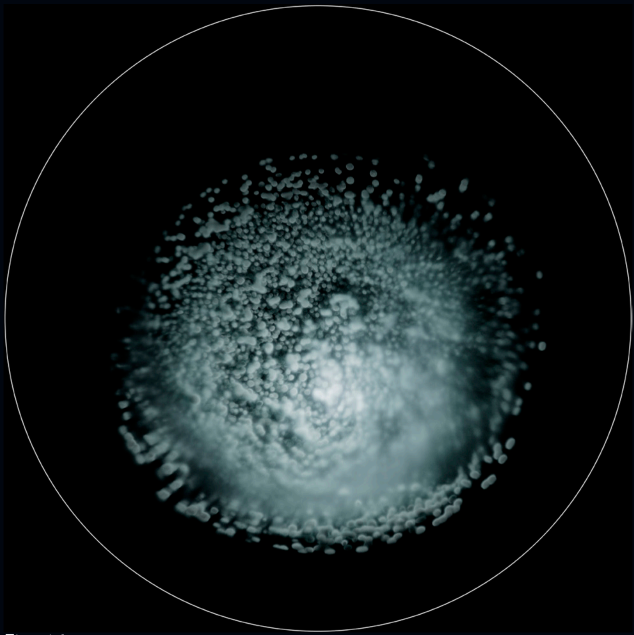


Fig. 46.

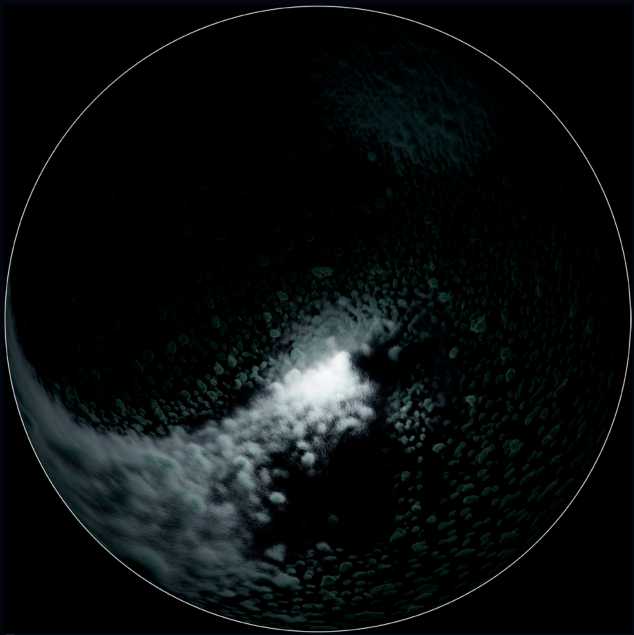


Fig. 47.


Fig. 48.

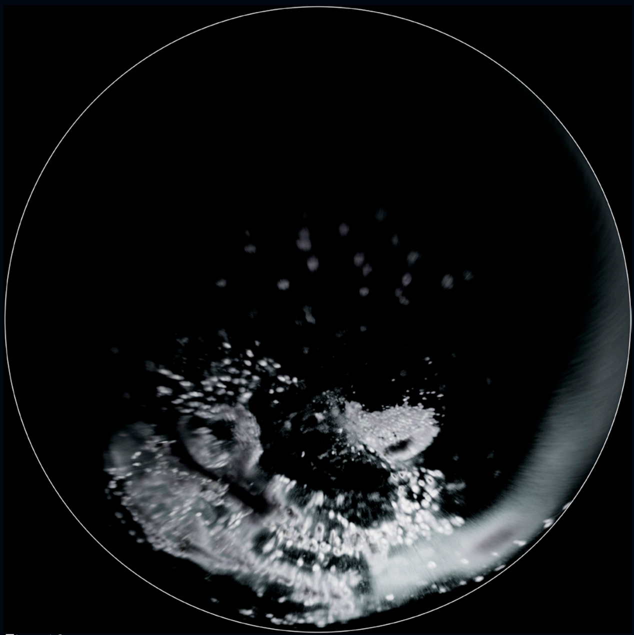


Fig. 49.


Fig. 50.

Fig. 45. Zebrafish development. Dataset credit: Ph.D. Philipp Keller, HHMI Janelia Research Campus.

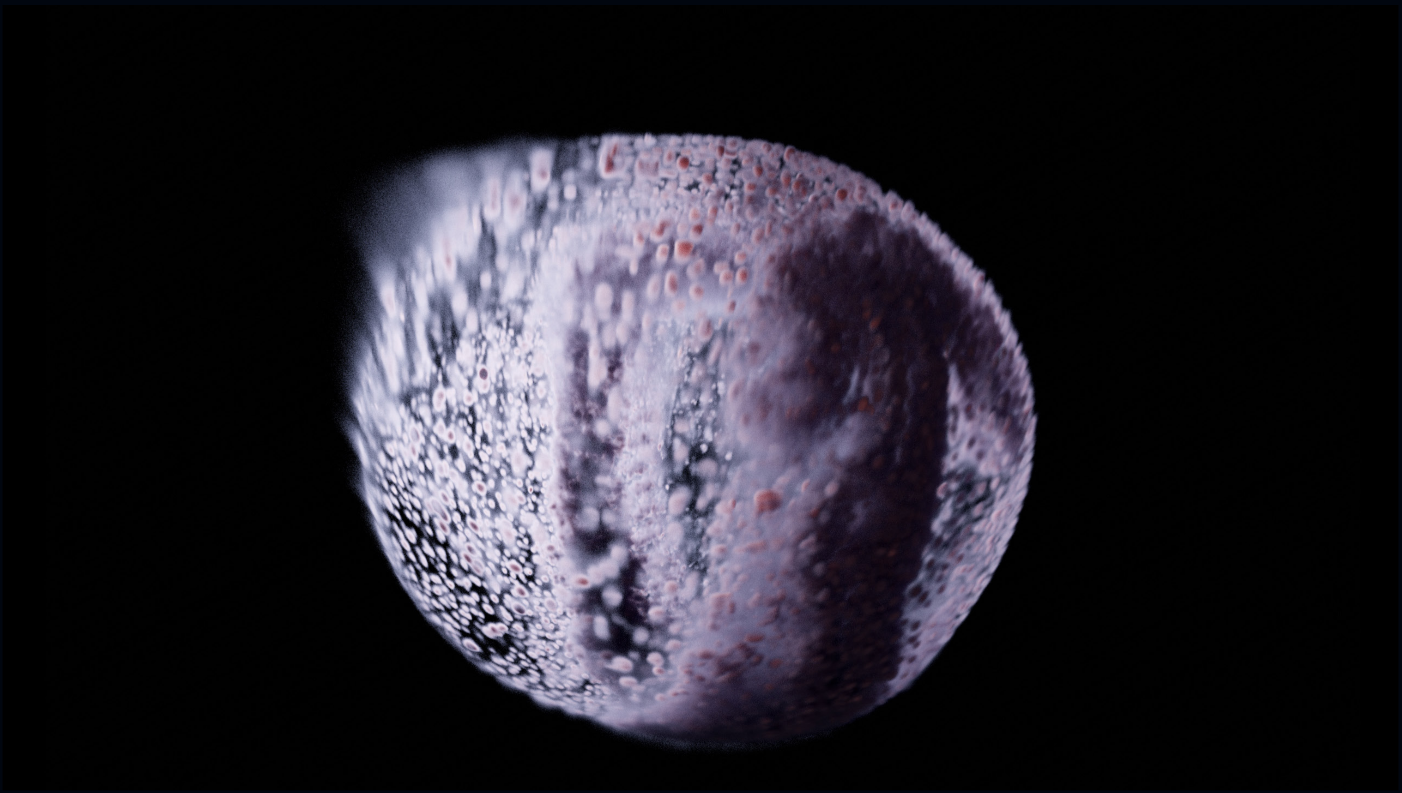
Fig. 46. Zebrafish development. Dataset credit: Ph.D. Philipp Keller, HHMI Janelia Research Campus.

Fig. 47. Zebrafish development. Dataset credit: Ph.D. Philipp Keller, HHMI Janelia Research Campus.

Fig. 48. Zebrafish development. Dataset credit: Ph.D. Philipp Keller, HHMI Janelia Research Campus.

Fig. 49. Zebrafish development. Dataset credit: Ph. D. Matyas Molnar, BioVis platform, Uppsala University.

Fig. 50. Zebrafish development. Dataset credit: Ph. D. Matyas Molnar, BioVis platform, Uppsala University.



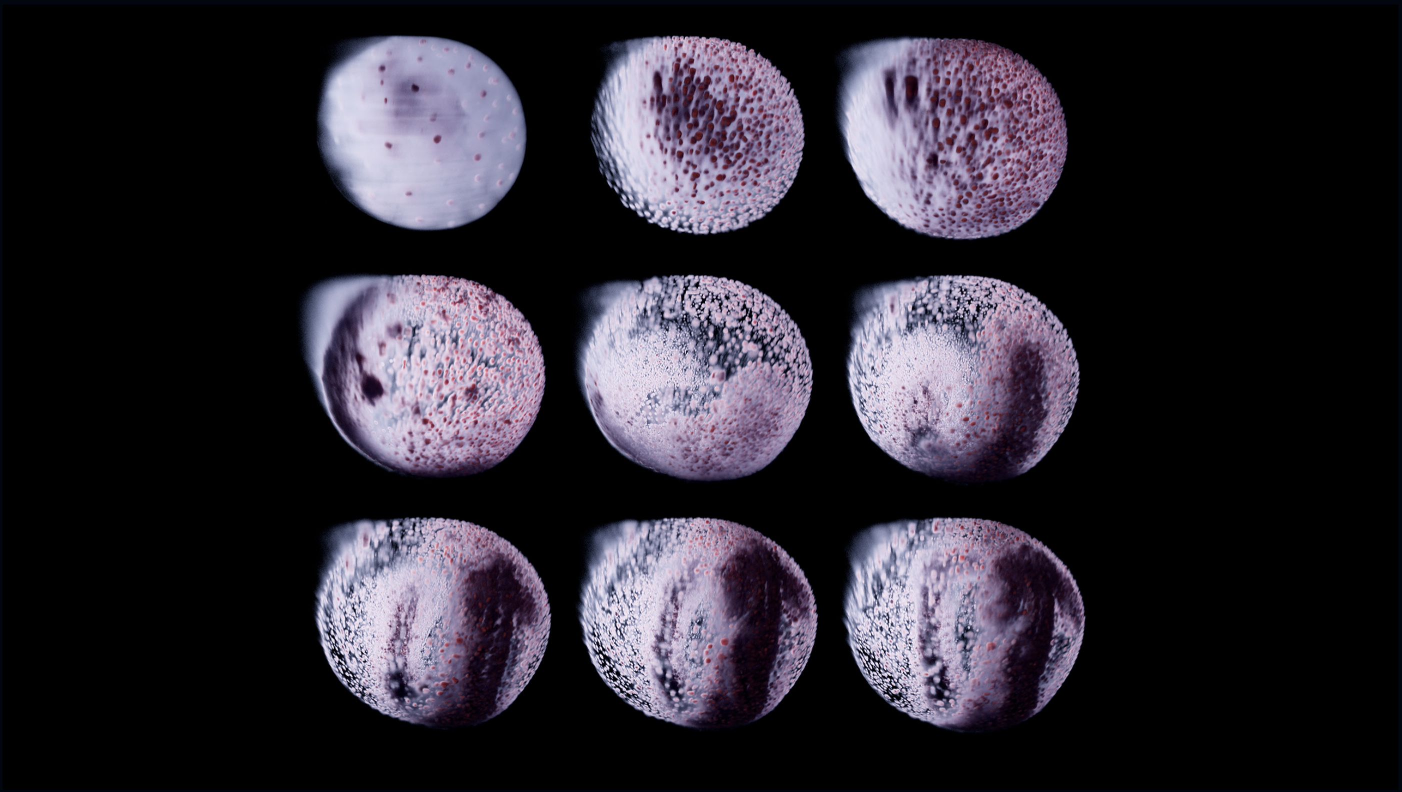


Fig. 51. Zebrafish embryo developing over time. Dataset credit: Ph.D. Philipp Keller, HHMI Janelia Research Campus.

3.6.3 REPURPOSING RESEARCH DATA

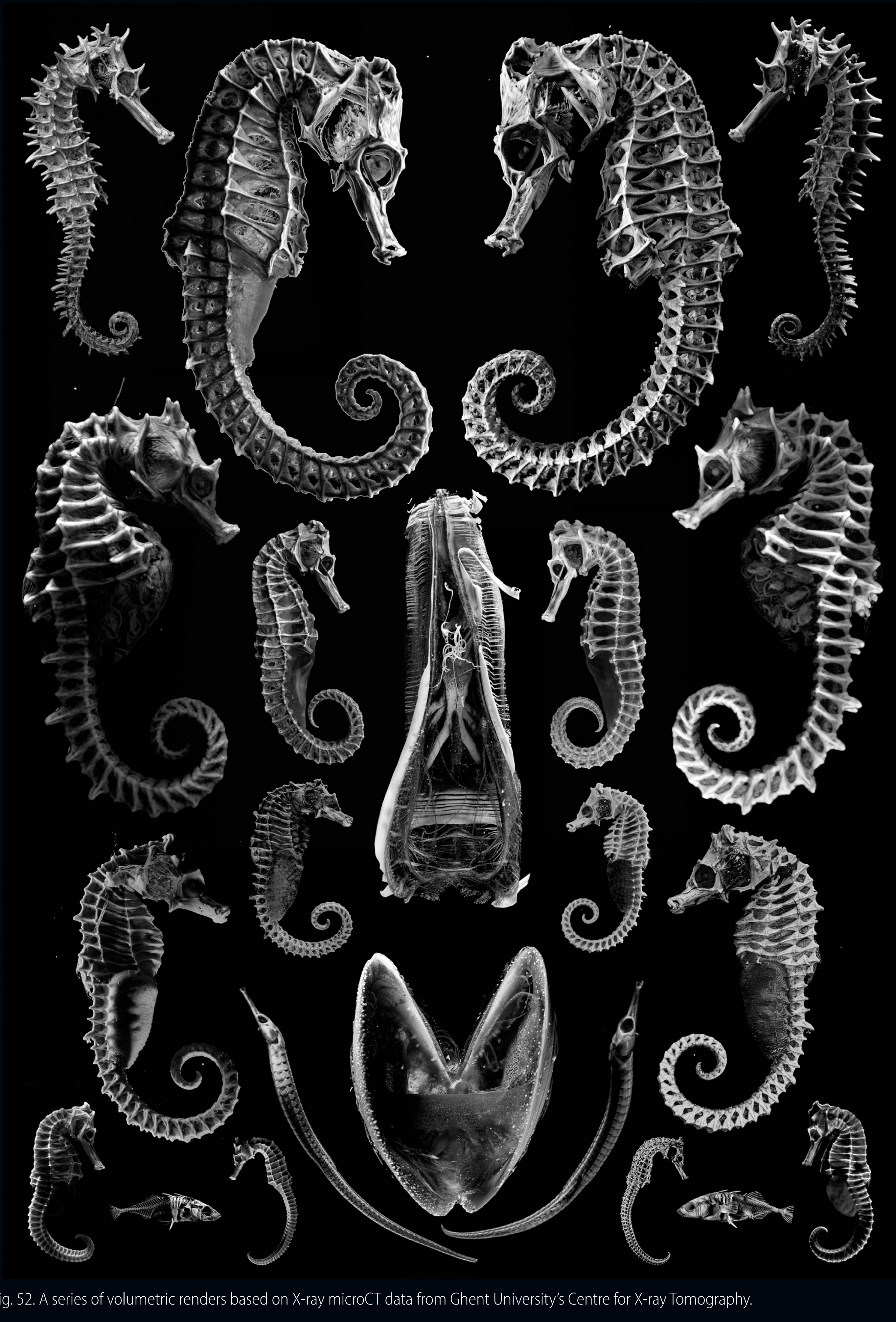


Fig. 52. A series of volumetric renders based on X-ray microCT data from Ghent University's Centre for X-ray Tomography.

3.6.3 REPURPOSING RESEARCH DATA

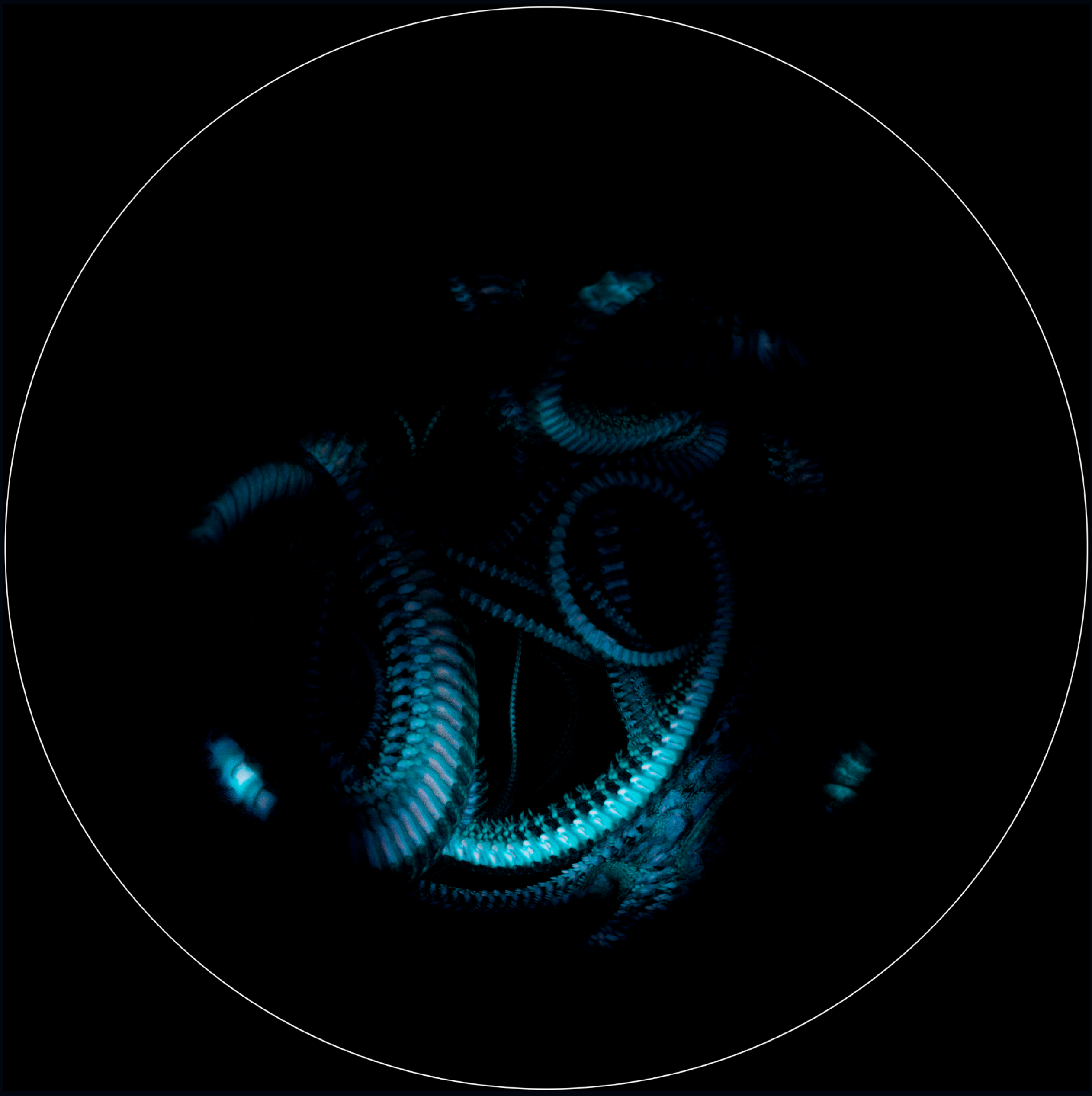
"The Embrace of the Ocean" utilizes a number of X-ray microCT datasets that were not produced with this film in mind, but rather for various research purposes, for example for detecting microplastic in filter-feeding bivalves. These datasets were provided by Ghent University.

Ghent University's Centre for X-ray Tomography has supported our work for years by sharing with us interesting datasets as well as scanning our own samples. Their data has been invaluable for testing and developing our own volume rendering tool and enabling us to develop working practices for bringing volumetric data into cinematic context, both in traditional flat screen and fulldome format.

Datasets provided by Ghent University make up half of the opening title sequence of the film and they are present again later in the film as a sequence of dive bys featuring echinoderms and seahorses. This sequence works as a passage between two scenes in the film: a shallow ocean floor at night and a remotely operated vehicle working several kilometers deep on the sea floor. Neither the night dive footage nor the deep ocean research robot camera footage were filmed with lenses suitable for dome-content production. Both scenes are crucial in the film, they are somewhat lengthy, and they were to be shown back-to-back. The worry was that the audience would lose the feeling of being immersed in the film if most of the dome would stay dark for extended periods of time.

During the principal photography stage of the film's production, every single dive was an important one. During the night diving phase, we had spent a portion of the dives filming with Boxfish 360 in anticipation for a situation where we needed to fill the whole dome with nighttime footage. The spotlight-lit Boxfish footage didn't test well in the dome, so I created a digital spotlight, matching in style our own night dive spotlights and the research robot's light rig, so that we could "dive" into the large variety of marine data received from Ghent University, lit in a similar fashion to the live footage.

Volumetric datasets provide exciting possibilities for a documentary filmmaker. They act almost as a treasure chest of found footage and repurposing datasets outside of their original use makes it possible to create cinematic scenes that would be completely outside of the scope of a normal film project, both due to restricted access to the scientific samples, or simply not being aware of their existence in the first place and budgetary reasons. Acquiring X-ray tomographic datasets can be very costly, and collecting, staining and preserving samples requires special training and equipment.



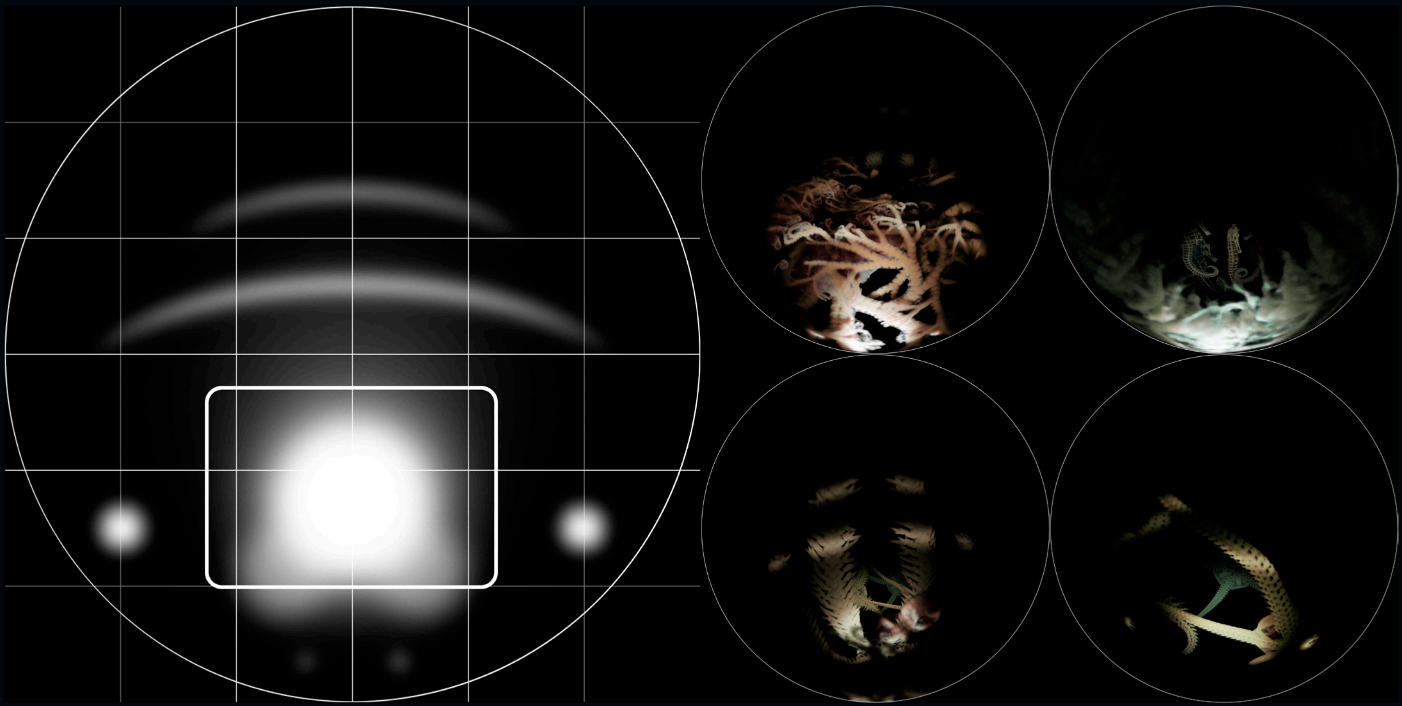


Fig. 53. A series of volumetric renders of X-ray microCT data. Datasets provided by Ghent University Centre For X-ray Tomography.

4 CONCLUSIONS

Creating cinematic content for the fulldome format is very different from creating content for traditional cinema screens. When hemispherical digital projection systems are built, material and equipment choices play an important part in determining screening quality. As a content-creator, recognizing the challenges inherent in dome design can help to work around some of the pitfalls.

Most decisions described here concentrate on maximizing image quality near the center vision of the audience at the cost of having less image elements at peripheral vision. Without conducting A/B testing on actual audiences, it is impossible to say whether the fulldome attending audience actually prefers to look at a more high contrast, vivid image with darker peripheral areas or if they would enjoy more a “milky”, or washed-out lower contrast image with the advantage of being surrounded with image elements all across the dome.

Future developments in planetarium design and materials might render the work outlined in this thesis less important or altogether unnecessary. If a solution is found to make the dome not scatter light on itself, but instead reflect most of it towards the audience, a lot of the headache of the hemispherical content-creator would vanish. Interesting designs to get around the problem have been explored: a dome where a real-time UV light projection renders parts of the dome more reflective than others synchronized with what is shown on screen has been proposed. The commercial viability of such a design is another question. (Rößner et al. 2016).

The series of tests conducted for this thesis compare extreme, hypothetical scenarios: the whole back half of the dome being either filled with black pixels or white pixels, for example. Most of the footage created for the film did not feature such extreme contrast. Having said that, several of the real-world scenarios enountered during the film’s production did overexpose the cameras’ sensors heavily and in most cases the problem areas did present themselves in the back half of the dome. Partially for this same reason, landscape shots on dry land were excluded from the film completely.

The Finnish fulldome film production scene is extremely marginal. Heureka’s planetarium sits next to the Tikkurila train station and enjoys large daily audiences visiting the science centre year-round. The planetarium cinema access is included in the general admittance to the science centre, and 3 to 4 different films are playing at the planetarium at any given day.

A fulldome show at The Finnish Science Centre will receive audience numbers in the tens of thousands over its screening life.

Between the premiere of *"The Embrace of the Ocean"* on 15 March 2019 and end of July 2019, the film was seen by approximately 58 000 people, or about 30% of the total science centre visitors (The Finnish Science Centre, internal statistics report, summer 2019).

For context, The Finnish Film Foundation lists the top 10 most watched Finnish documentary films in cinemas in the last fifty years to be the following:

1. Järven tarina, 187185, 2016
2. Sel8nne, 130530, 2013
3. Metsän tarina, 90544, 2012
4. Reindeer-spotting - pako Joulumaasta, 63654, 2010
5. Saimaa-ilmiö, 52677, 1981
6. Miesten vuoro, 49911, 2010
7. The Real McCoy, 42756, 1999
8. Eput, 40514, 2016
9. Vesku, 37448, 2010
10. Ramses ja unet, 35229, 1982

(The Finnish Film Foundation website, 16.10.2019)

While the numbers are not directly comparable, they show that Heureka's planetarium as a single cinema screen draws large crowds annually and should be considered a serious distribution channel for Finnish film. *"The Embrace of the Ocean"* places well in the domestic documentary film scene when measured by the size of cinema-going audience.

While audience numbers are large, the steep learning curve in getting into fulldome content-creation, the challenges in obtaining or developing the right kind of equipment at an affordable cost and lack of domestic tradition and know-how create obstacles for a Finnish fulldome scene to emerge.

While Heureka has been open to screening domestic-produced nature documentary content, the vast majority of planetarium content world-wide is concentrated around astronomical subjects. Fulldome Database lists 185 fulldome shows under the 'documentary' tag, of which approximately 75% are related to astronomical subjects, compared to just 2-3 shows being related to life in the Earth's oceans. (Fulldome Database website, 4.11.2019). However, digital fulldome cinema scene is a young field globally, and future developments in screening quality and availability of both affordable camera equipment for high-quality fulldome content creation and locations for screening fulldome content may shift matters towards more volume and variety in produced content.

Color grading, composition and title and end credit design among other filmmaking aspects are important in traditional filmmaking. Their role in fulldome content production is just as important, but for somewhat different reasons. The balance between low-light-high-contrast and bright-light-low-contrast projections and the audience's feeling of immersion created by filling the dome with content vs. dimming or cutting out peripheral visual cues in order to maximize image quality at the dome's sweet spot is a complicated balancing act. This challenge can be prepared for by becoming familiar with the Dome Master format before making costly decisions about camera equipment, software, animation style and what topics to include in a film's script. While the Dome Master format acts as a unifying standard between the world's fulldome theatres, screening quality between different domes may vary considerably.

Within the scope of this production, some suitable types of data were not included into the film due to the challenging nature of creating content for the Dome Master format. Namely the various three-dimensional datasets that could have been used to contextualize the film's locations and highlight the challenges the world's oceans are facing as a result of increased global human activity. The film shows humpback whales and mentions their long migration, but does not visualize it. Natural Earth Data or NOAA data could have been used to visualize not only whale migration paths, but ocean bathymetry or currents, weather, filming locations highlighted on a three-dimensional model of planet Earth, to name a few examples.

Many fulldome shows are largely based on virtual models of the Earth and a virtual camera visiting Earth's different locations and the solar system's various celestial bodies. A notable, missing topic in the film is underwater noise pollution, an interesting visualizing challenge of a little talked about and only recently studied phenomenon. Baltic sea's first noise pollution map was created only in 2016 by The Finnish Environment Institute (Finnish Environment Institute website, 25.01.2017), while *"The Embrace of the Ocean"* had already been in planning stages for some time.

Digital fulldome planetariums are a young branch in the already relatively long history of cinema. Future developments in planetarium design, camera equipment and software will probably make it more accessible and worthwhile for filmmakers to engage in. Recent advancements in virtual reality hardware, software and content-creation may lend their hand in shaping the field of hemispherical cinema, as well. In the future, the problem of cross-reflection will hopefully have been solved and fulldome content can be designed without such strict limitations on what can be projected on the screen, but until then, this thesis will hopefully inspire the reader on their way to contributing to the field of digital fulldome cinema.

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ADDITIONAL IMAGE CREDITS

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Render of kilkki (Saduria entomon). Dataset credit: University of Helsinki microCT Laboratory.

Page 27
Render of bivalve. Dataset credit: Ghent University Centre for X-ray Tomography.

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Two underwater photographs. Photo credit: Pekka Veikkolainen.

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Photograph of yellowstripe scad (Selaroides leptolepis). Photo credit: Pekka Veikkolainen.

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Still frame of aerial video. Image credit: KopterCam.

Page 50
Still frame of microplastic under a microscope. Facilities: Tvärminne Zoological Station.
Microplastic samples: Finnish Environment Institute / Pinja Näkki.

Page 55
Still frame of kilkki (Saduria entomon). Image credit: Leading Note Pictures Oy.

Page 61
Render of zebrafish. Dataset credit: Ph. D. Matyas Molnar, BioVis platform, Uppsala University.

Page 67
Render of bivalve. Dataset credit: Ghent University Centre for X-ray Tomography.